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**A . Report Title: Best Manufacturing Practices: Report of Survey Conducted at NASA Kennedy Space Center, Cape Canaveral, FL**

**B. DATE Report Downloaded From the Internet: 12/19/01**

**C. Report's Point of Contact: (Name, Organization, Address, Office Symbol, & Ph #): Best Manufacturing Practices**
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**D. Currently Applicable Classification Level**: Unclassified

**E. Distribution Statement A**: Approved for Public Release

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*REPORT OF SURVEY CONDUCTED AT*

**NASA**
**KENNEDY SPACE CENTER**
**CAPE CANAVERAL, FL**

*OCTOBER 1996*

# ***Best Manufacturing Practices***

**BEST MANUFACTURING PRACTICES CENTER OF EXCELLENCE**
**College Park, Maryland**

# Foreword

This report was produced by the Best Manufacturing Practices (BMP) program, a unique industry and government cooperative technology transfer effort that improves the competitiveness of America's industrial base both here and abroad. Our main goal at BMP is to increase the quality, reliability, and maintainability of goods produced by American firms. The primary objective toward this goal is simple: to identify best practices, document them, and then encourage industry and government to share information about them.

The BMP program set out in 1985 to help businesses by identifying, researching, and promoting exceptional manufacturing practices, methods, and procedures in design, test, production, facilities, logistics, and management – all areas which are highlighted in the Department of Defense's 4245-7.M, *Transition from Development to Production* manual. By fostering the sharing of information across industry lines, BMP has become a resource in helping companies identify their weak areas and examine how other companies have improved similar situations. This sharing of ideas allows companies to learn from others' attempts and to avoid costly and time-consuming duplication.

BMP identifies and documents best practices by conducting in-depth, voluntary surveys such as this one at NASA Kennedy Space Center (KSC), Cape Canaveral, Florida conducted during the week of October 21, 1996. Teams of BMP experts work hand-in-hand on-site with the company to examine existing practices, uncover best practices, and identify areas for even better practices.

The final survey report, which details the findings, is distributed electronically and in hard copy to thousands of representatives from government, industry, and academia throughout the U.S. and Canada – *so the knowledge can be shared.* BMP also distributes this information through several interactive services which include CD-ROMs, BMPnet, and a World Wide Web Home Page located on the Internet at http://www.bmpcoe.org. The actual exchange of detailed data is between companies at their discretion.

KSC has the opportunity to be the global leader and facility of choice for space launch operations and payload processing. Clearly the facilities, infrastructure, capabilities, and expertise that exist at KSC are world-class and generally unequaled. The challenge in capitalizing on this opportunity is to deal effectively with the sweeping changes of large scale privatization which are occurring as KSC redefines itself. Among the best examples were KSC's accomplishments in instrumentation and control; human factors event evaluation model; technical documentation system; payload operations network and network control center; space shuttle logistics; benchmarking; and weather support.

The Best Manufacturing Practices program is committed to strengthening the U.S. industrial base. Survey findings in reports such as this one on NASA Kennedy Space Center expand BMP's contribution toward its goal of a stronger, more competitive, globally-minded, and environmentally-conscious American industrial program.

I encourage your participation and use of this unique resource.

Ernie Renner
*Director*, Best Manufacturing Practices

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# Section 1

# *Report Summary*

## *Background*

The National Aeronautical and Space Administration (NASA) John F. Kennedy Space Center (KSC) was established at Cape Canaveral, Florida in 1962. As America's only manned spaceport, KSC currently employs 2,200 civil servants and 12,000 contractors. Its fiscal budget was $1.3 billion in 1995. Surrounded by the Merritt Island National Wildlife Refuge, KSC encompasses 140,000 acres of land and 8 million square feet of building area. The facility provides prelaunch checkout, assembly, testing, and processing of the space shuttle fleet and of the payloads that fly aboard, as well as shuttle launch, landing, and solid rocket booster recovery operations.

In the present political environment which is embracing a strong policy to reduce government, balance the Federal budget, and privatize to the maximum extent, KSC faces major challenges. These include reducing its workforce, privatizing the Space Shuttle program, and redefining its role and mission. In light of this new direction, KSC continues to commit to excellence in the quality of its products and services for its many customers. Among the best examples were KSC's instrumentation and control; human factors event evaluation model; technical documentation system; payload operations network and network control center; space shuttle logistics; benchmarking; and weather support.

KSC's ad hoc concurrent engineering development teams produce quality instrumentation and controls at the lowest costs available. Through streamlining techniques, real-time measurements, non-program funding, and customer involvement, KSC has successfully produced financial savings and resolved potential life-threatening situations. Examples include Automated Window Inspection System, Hazardous Gas Detection System, Hydrazine Vapor Detection, and Real-time Contamination Monitoring. With a significant annual cost savings, KSC leads the world in the enhancement of specialized instrumentation and control development.

The typical reactive approach to incident reporting and resolution usually does not investigate the human factor elements, nor does it permit knowledge gain from past incidents to be incorporated. Instead, KSC developed the Human Factors Event Evaluation model as a continuous improvement tool. By using the model, KSC reanalyzed 25 previous incidents and was able to test both the validity of the model, as well as identify valuable, additional root cause data. The Human Factors Event Evaluation model provides greater understanding of the interrelationship between humans and processes, new insights into root causes contributing to errors, and better capability for analyzing trends.

Payloads Processing uses more than 5,000 documents in its operations, representing more than 30 different types of documents. Upon analyzing the documentation flow, KSC recognized the need to create a central repository, establish standard formats, and eliminate the inaccurate tracking, revisions, and distribution of its documents. To resolve this problem, KSC incorporated the Technical Documentation System. This electronic management system provides document templates, electronic review, document modification, activity tracking, simple or complex searches, and multiple viewing levels.

Isolated networks and diverse applications existed throughout KSC. Lack of configuration control, adequate budgets, unique dedicated wiring, and proprietary protocols signaled a need for improvement. KSC improved its network capabilities by establishing the Payload Operations Network (PON) and the Network Control Center (NCC). Comprised of several local networks tied together, PON interconnects all the payload facilities into one Local Area Network (LAN). In addition, PON provides network services and integrated information technology support. A centralized NCC controls operation and maintenance of the network and provides a customer help desk.

Overwhelming best describes the shuttle logistical task in magnitude and complexity. More than 250,000 part numbers exist for each orbiter and related ground support equipment. In addition, KSC uses multiple duplication of some parts, maintains and distributes spares, and monitors 52 repair contracts. To handle this enormous job, KSC relies on numerous management methodologies, unique databases, and discrete simulation models. Benefits include a decrease from 120 per year to 8 per year in the cannibalization rate, an increase from

90% to 98% in furnishing spares from on-hand supplies, and the elimination of Capability Retention Contracts (industry contracts are maintained solely to retain unique capabilities).

KSC established a Benchmarking Network in collaboration with its major contractors and pioneered consortium benchmarking techniques to reduce the cost of benchmarking studies. In general, KSC determines the amount of resources to invest by estimating the potential return on the investment and by considering the criticality of the process, the process stability, the availability of documentation, and the cost of implementing process change. After a successful government property benchmarking study, several organizations have reported significant cost avoidance and reductions in property loss reports. As a result, KSC was designated as the leader in agency benchmarking by NASA, and received a 1995 Silver Medal Benchmarking Award in Applied Research from the International Benchmarking Clearinghouse.

Spacecraft operations are extremely weather sensitive. In addition, forecasting weather in the Cape Canaveral area is complicated by the surrounding landscape, the jet streams, the lack of sensors to the east, and the fact that this area is the lightning center of the United States. KSC established its Weather Office as the centralized coordinator to govern the space program on weather-related issues such as infrastructure projects, constraints, emergencies, and technical expertise. To accomplish this, the Weather Office uses a multi-agency infrastructure comprised of wind towers; lightning detection equipment and algorithms; data acquisition and display systems; hazard models; and various sondes and spheres.

KSC has the opportunity to be the global leader and facility of choice for space launch operations and payload processing. Clearly the facilities, infrastructure, capabilities, and expertise that exist at KSC are world-class and generally unequaled. The challenge in capitalizing on this opportunity is to deal effectively with the sweeping changes of large scale privatization which are occurring as KSC redefines itself. The BMP survey team considers the following practices to be among the best in industry and government.

## *Best Practices*

The following best practices were documented at KSC:

## *Information*

The following information items were documented at KSC:

## *Point of Contact*

For further information on items in this report, please contact:

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# Section 2

# *Best Practices*

## *Design*

### Automated and Intelligent Systems

KSC shares its state-of-the-art automated and intelligent systems with the private sector through technology transfer activities. Although some customizing was necessary due to NASA's unique ground applications, the use of commercial off-the-shelf (COTS) products expedited the overall development process of the automated and intelligent systems. Areas of development included teleoperated and autonomous control systems; automated systems simulation; and task planning. Because NASA uses hazardous material, safety was a concern. However, this was resolved through the use of robotic systems for these types of environments.

KSC uses the latest technology available to develop its automated and intelligent systems. These include Internet tools which are available at no cost via downloading, and COTS software tools such as Labview for data acquisition and control. These permit KSC to access the latest technologies by using the most cost-effective methods.

One example of an automated and intelligent system is the Portable Hepa Filter Inspection System. Knowing that clean room environments are critical in maintaining contaminant-free payloads, KSC developed the automated Portable Hepa Filter Inspection to inspect the air filtration filters in payload changeout rooms. By automating this process, KSC achieved increased safety, reduced costs, and improved quality. To further enhance payload processing, KSC also implemented a COTS, autonomous Mobile Cleaning Robot for cleaning the hard floors of a clean room. These two systems have resulted in a higher quality, more-efficient cleaning process with reduced costs that can be utilized in other NASA operations or the private sector for clean room applications.

The method and process of waterproofing the shuttle's thermal tiles provide the best example of KSC's automated and intelligent systems. At a cost savings of more than $200 thousand annually, the waterproofing system (Figure 2-1) injects the hazardous, waterproofing substance into the tiles and performs the tile inspection, which becomes a baseline for future degradation analysis. This new process improves worker safety; reduces costs; enhances data collection; baselines the orbiter's lower-surface tiles; and through technology transfer, enables other process automations with little development costs.

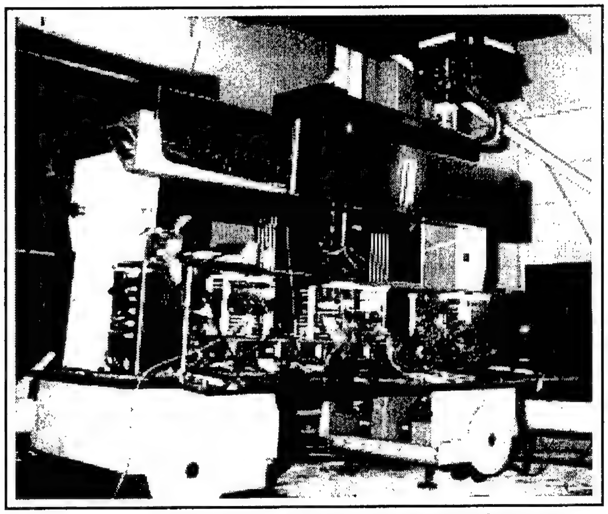


***Figure 2-1. Automated Tile Processing System***

KSC's automated and intelligent systems have saved time and money, improved quality, and increased safety. Enhancements such an Internet tools, alignment tools, and robots supplement these automated and intelligent systems in many ways. Real-time test data is now available via the Internet to other NASA centers and contractors. Internet tools also support Rockwell's Orbital Maneuvering System Testbed for New Launch Vehicle Development. Many alignment tools improve the accuracy and cycle times of systems. Robots improve the accuracy and safety of visual inspections. These state-of-the-art systems, developed by KSC, would be valuable manufacturing technologies throughout the United States.

### Information Systems Laboratory

The Information Technology (IT) requirements for NASA's largest launch site are quite complex, and demand continuous evaluation of new IT capabilities. KSC's Information Systems Laboratory stays up-to-date on leading-edge IT, so NASA can quickly and efficiently implement new and effective solutions as requirements change.

Before the Information Systems Laboratory existed, numerous obstacles hindered on-site customers who tried to contact off-site facilities through data communications. These obstacles included incompatible networks, lack of connectivity with the outside world, and lack of staff to assist the customer. The Information Systems Laboratory established an Internet connectivity and provided standard, Internet services for KSC's customers. The staff continues to maintain expertise on multiple platforms and operating systems, so that quick solutions are available to meet each customer's unique data communication needs.

To capitalize on modern computing systems, the Information Systems Laboratory researched different ways of automating information systems. Redundant systems which automatically transfer resources between components during failures are able to contact staff members for assistance. These systems virtually eliminate downtime and reduce manpower requirements by eliminating the need for continuous monitoring.

In addition, the Information Systems Laboratory operates KSC's website through the World Wide Web. KSC's website provides more than 28,000 pages of information to a diverse community of users, ranging from the general public to its own employees. It would be virtually impossible to support a staff to manually update this information in a timely fashion. Instead, the Information Systems Laboratory developed a unique software, using the perl language, which automatically converts e-mail messages and other sources of information to Hyper Text Markup Language documents. This software also performs regular-expression searches to locate text strings which can automatically be converted into hyperlinks leading to other documents. This development effort resulted in a very large, but extremely dynamic and up-to-date website, and requires only a minimum of human intervention.

To keep up with the demand, which has peaked at 4 million accesses per month, KSC uses a dual processor DEC Alpha with 640 MB of RAM and 24 GB of disk space to communicate with an external 2 MB/s E-2 circuit. The server distributes the workload across 13 other systems through one Fiber Distributed Data Information and three Ethernet networks.

## Instrumentation and Control

KSC is responsible for instrumentation development, qualification, standardization, characterization, testing, and problem solving for the Nation's manned spaceflight program. This responsibility includes determining ways which KSC can improve the cost effectiveness of instrumentation deployment. By using real-time measurement techniques, KSC has realized significant savings through reduced recurring costs of operation, while maintaining the required flight rates, even with mandated manpower reductions. KSC has reduced the costs to the shuttle, payloads, and space station programs by using non-programmatic funding sources to solve shuttle, payloads, and space station problems.

Many organizations approach project initiation and problem solving in a reactive manner. KSC's Instrumentation Development Laboratory's approach is based on customer input detailing process improvement requirements and provides customer benefits through time and money-saving procedures. This development process at KSC begins with assisting the customer in documenting requirements for their specific needs. In turn, the customer becomes involved as part of the design team and participates in frequent, informal, design reviews. This has proved to be a beneficial way to meet customers' technical needs and reduce data collection time cycles, producing unforeseen cost savings.

KSC's fast response time to problem solving in sensor development is remarkable. Typical response times for urgent problems are one to three days, which may include travel time to other NASA Centers or contractor plants. By eliminating the requirements of lengthy analysis, the launch team and other NASA centers' requests are acted upon immediately. This has produced millions of dollars in cost savings due to solutions that reduce downtimes related to launch readiness.

By applying this method, KSC has created individual instrumentation which has produced substantial cost savings, such as:

- Automated Window Inspection System (Figure 2-2) at $5.6 million per year
- Hazardous Gas Detection System at $1.6 million

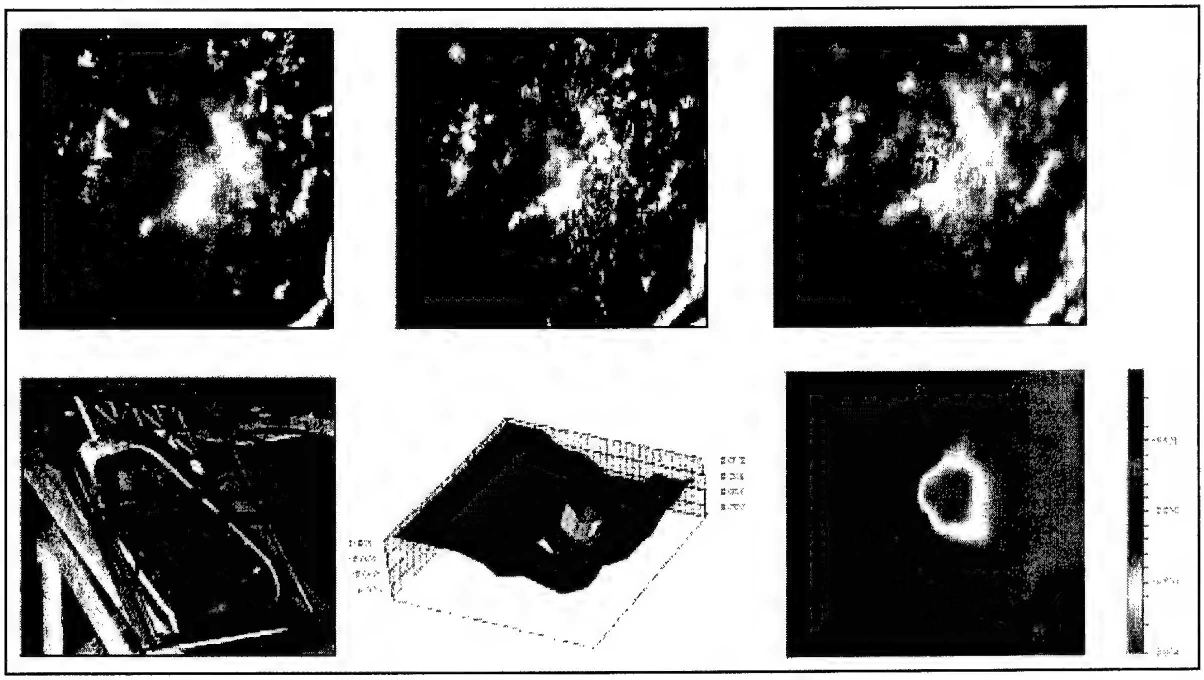


*Figure 2-2. Automated Window Inspection System*

- Launch Complex 39/SLF Meteorological System Upgrades at $1 million per mission
- Advanced Data Acquisition at $900 thousand per year
- Dimethyl Ethoxysilane (a shuttle tile water-proofing compound) Toxic Vapor Detection Carts at $400 thousand per year

Besides the financial savings, other developments have produced "Fastract Delivery", solving urgent problems and potential life-saving developments. Some of these accomplishments are:

- Laser Shearography (Figure 2-3) which detects unbonded areas of insulation on the External Tank, Remote Manipulator System, and other flight hardware
- Ultrasonic Leak Detection and Location (Figure 2-4)
- Hazardous Gas Detection System
- Portable 10 parts per billion Hydrazine Vapor Detectors

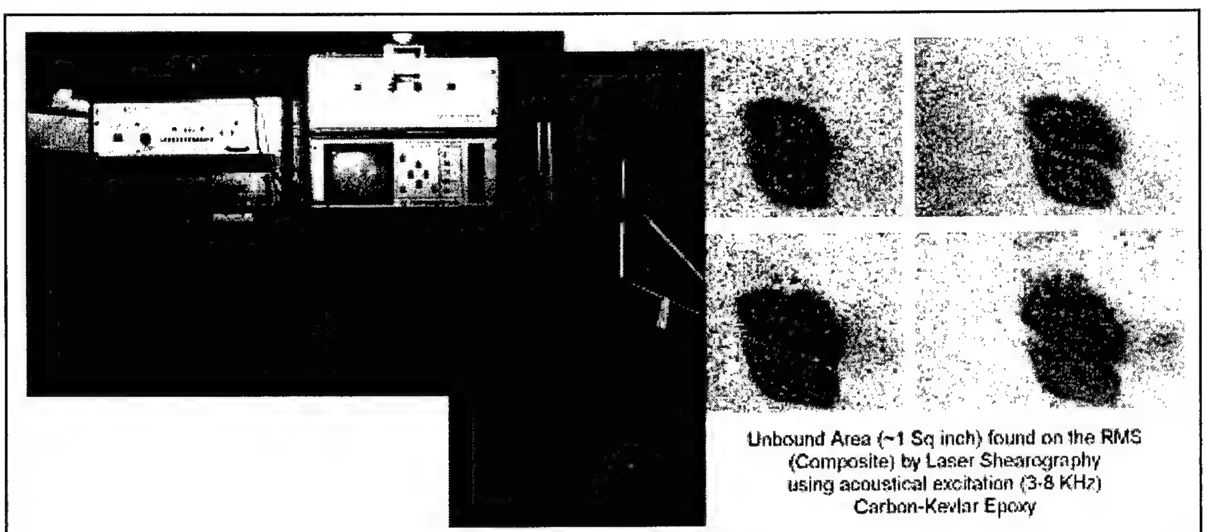



*Figure 2-3. Laser Shearography*

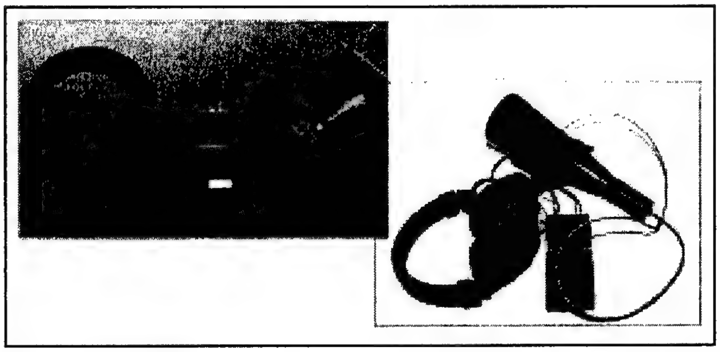


***Figure 2-4. Ultrasonic Leak Detection and Location***

- Real-time Contamination Monitoring
- Improved Hydrogen Leak Detectors
- Solid Rocket Booster O-ring Groove Inspectoscope

With significant annual cost savings, KSC leads the world in the enhancement of specialized instrumentation development. KSC's ad hoc concurrent engineering development teams work superbly to produce quality instrumentation at the lowest possible costs.

## *Test*

### Failure Analysis

The Materials Science Division's diverse workforce supports and handles the unique analysis requirements of KSC. Functions include chemical analysis, materials analysis, process evaluation, applications research, failure analysis, technical consultation, and technology transfer.

Heavily involved with industry, the Materials Science Division works in the development and use of corrosion and heat-resistant coatings and metal alloys. The Florida region combines heat, salt, and high humidity to form one of the most corrosive environments ever documented. The beach corrosion test site, one of the facilities, provides performance history on coatings and alloy materials. There are thousands of test specimens at the corrosion test site, some dating back almost 30 years. Specialists at the Materials Science Division continually provide coating research, and periodically publish technical articles in the *Journal of Protective Coatings and Linings, Material Performance*, and various other industrial and internal publications.

Of the 8,000 different jobs processed every year at the Materials Science Division, about 1,000 are failure analysis jobs with the remainder comprised of physical analysis and chemical testing functions.

In addition to KSC, the Materials Science Division also performs work for the Air Force; the Navy; the National Transportation Safety Board; the Bureau of Alcohol, Tobacco and Firearms; other federal and state agencies; and the surrounding industrial community. The failure analysis functions at KSC provide a critical, corrective-action operation which helps make the space program a successful one.

### PCGOAL Shuttle Data Monitoring System

Initially started by KSC in 1990, the Personal Computer Ground Operations Aerospace Language (PCGOAL) provides remote sites with a system for monitoring space shuttle data. The system is low-cost, near real time, and PC-DOS based. It was developed at KSC for Dryden Flight Research Facility to provide visibility for the space shuttle data. Once the system was initiated and operational, NASA technical experts recognized its applicability to the main-firing, control room at KSC.

PCGOAL enables technicians to plot data in real-time by using the trend data and test results. Previously, the system needed to be off-line, the operating application or environment shut down, and the data input transitioned as a separate operation. With PCGOAL, KSC now has a stand-alone system with trend-analysis capability which does not require other systems or capabilities to be shut down.

PCGOAL benefits KSC's launch director, decision-makers, and problem-solvers through its ability to provide real-time information on easy-to-see terminals. Real-time information helps KSC personnel respond to emerging events immediately. Presently, this user-friendly system is being implemented by other NASA field centers. NASA Johnson Space Center derived one of its currently-used data monitoring systems, called XGOAL, from KSC's PCGOAL. XGOAL is, in fact, a UNIX version of PCGOAL.

Future plans include migrating PCGOAL to other operating systems; it is ready for Windows 95, and a JAVA version has been prototyped. Additional PCGOAL users include the NASA Johnson Space Center Evaluation Room; NASA Marshall Space Flight Center, Huntsville Operations Support Center; NASA Stennis Space Center, Space Shuttle Main Engine Project, as well as Pratt & Whitney in Palm Beach, Florida and Rocketdyne in Canoga Park, California.

## Production

### Automated Problem and Discrepancy Reporting Program

KSC uses an automated process to document Problem Reports (PR) and Discrepancy Reports (DR) on the servicing and modification of each space shuttle prior to its next mission. The previous method can best be described by an example. The Thermal Protective System consists of 30,000 to 50,000 individual, unique tiles or blankets. Upon inspection, any discrepancies were documented by notes on a clipboard. These notes, unique to each inspector, introduced non-standardized descriptions. The inspectors would later transcribe these notes to an official report. This serial duplication of effort consumed time, provided an opportunity for transcription error, and perpetuated unverified, invalid, and inconsistent data. The newly-implemented automated process uses a Toshiba T200CS 486/40 pen-based computer with 20 MB of RAM, Microsoft DOS 6.22, and Microsoft Pen for Windows 1.0.

The automated PR/DR program features on-screen pop-ups, check boxes, and draw screens. The program allows users to enter damage-description data with virtually no keyboard input. Screen pop-ups (Figure 2-5) provide standardized lists and

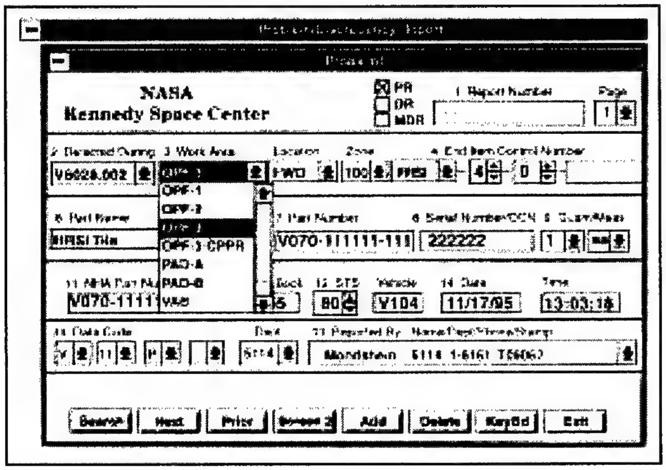



*Figure 2-5. Check Box Screen*

restrict the user to the displayed choices. Elements of artificial intelligence automatically change the configuration of the screen pop-ups based on the selected user-input. The graphics capability allows the user to handdraw a picture of the tile damage directly on the computer screen (Figure 2-6). The software saves the image and later prints it out on the PR/DR.

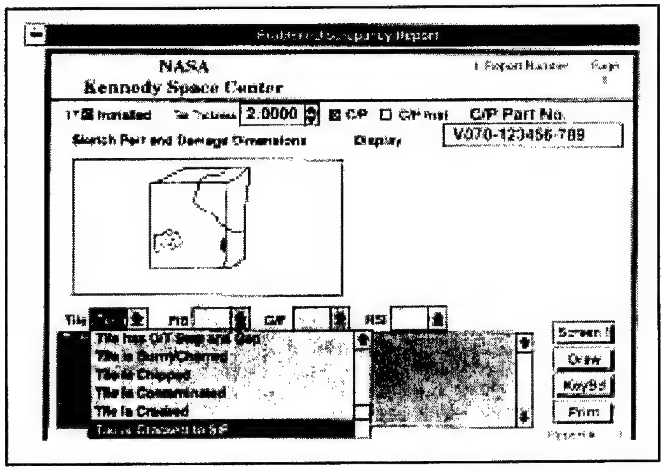



*Figure 2-6. Draw Screen*

Future plans include linking the pen-based computers to a server via a radio frequency Local Area Network (LAN). This will allow real-time printing of PRs and DRs, and simultaneous updating of several tracking databases including master scheduling and spares acquisition.

Tens to hundreds of labor hours; inventory ordering and retrieval time-and-cost; and further scheduling time will be saved by using this user-friendly, automated, pen-based computer system. KSC plans to expand this system to its propulsion, electrical, and mechanical inspection requirements.

### Ground Processing Scheduling System

KSC developed the Ground Processing Scheduling System (GPSS), an artificial-intelligence-based, work-scheduling tool, as part of its Integrated Work Control System (IWCS). Currently being used in its development stage, GPSS is the primary scheduling tool for supplementing the existing computer-aided, process-planning tools of the Orbiter Processing Facility. A KSC development team produced the GPSS based on initial scheduling algorithms developed by NASA Ames Research Center.

Influences on the complexity of the scheduling task include 24 major (most being in parallel)

subsystems connected with the orbiter configuration and resource constraints associated with the supporting tasks, frequent rescheduling due to unexpected events, and the need to communicate schedule information in a timely manner. The development team used the Ames constraint-based algorithms to model the temporal, configuration, and resource constraints of each processing activity. These models then compare individual task schedules, resolve conflicts, and produce schedules which contain minimal constraint violations.

Key milestones for 1996 and 1997 include completing the integration within the IWCS, reengineering the LISP-based software to a C++ version, and expanding the system to handle multiple flows. Future applications will include scheduling for the Vertical Assembly Building and the Launch Pad operations. KSC has granted a license to a software development company which has developed a commercial version of the program. The licensing rights are now nonexclusive, and KSC is interested in future licensing agreements with other interested commercial parties.

## Human Factors Event Evaluation Model

KSC's Shuttle Processing Human Factors team developed the Human Factors Event Evaluation model as a continuous improvement tool for discovering the underlying causes of human error. Not only does the model determine the underlying human factor causes of incidents after they happen, but it also trends when, where, and under what circumstances these incidents occurred. KSC expects this capability to enable the Shuttle Processing Operations to reduce the frequency and severity of future incidents.

Previously, most KSC incident reporting and resolution were reactive to events, with little emphasis or investigation on human factors elements and methods. Though this approach provided documentation and explanation, it did not allow KSC Shuttle Processing Operations to learn from past incidents, factor in what they had learned, nor apply that knowledge to areas beyond the one in which the incident had occurred.

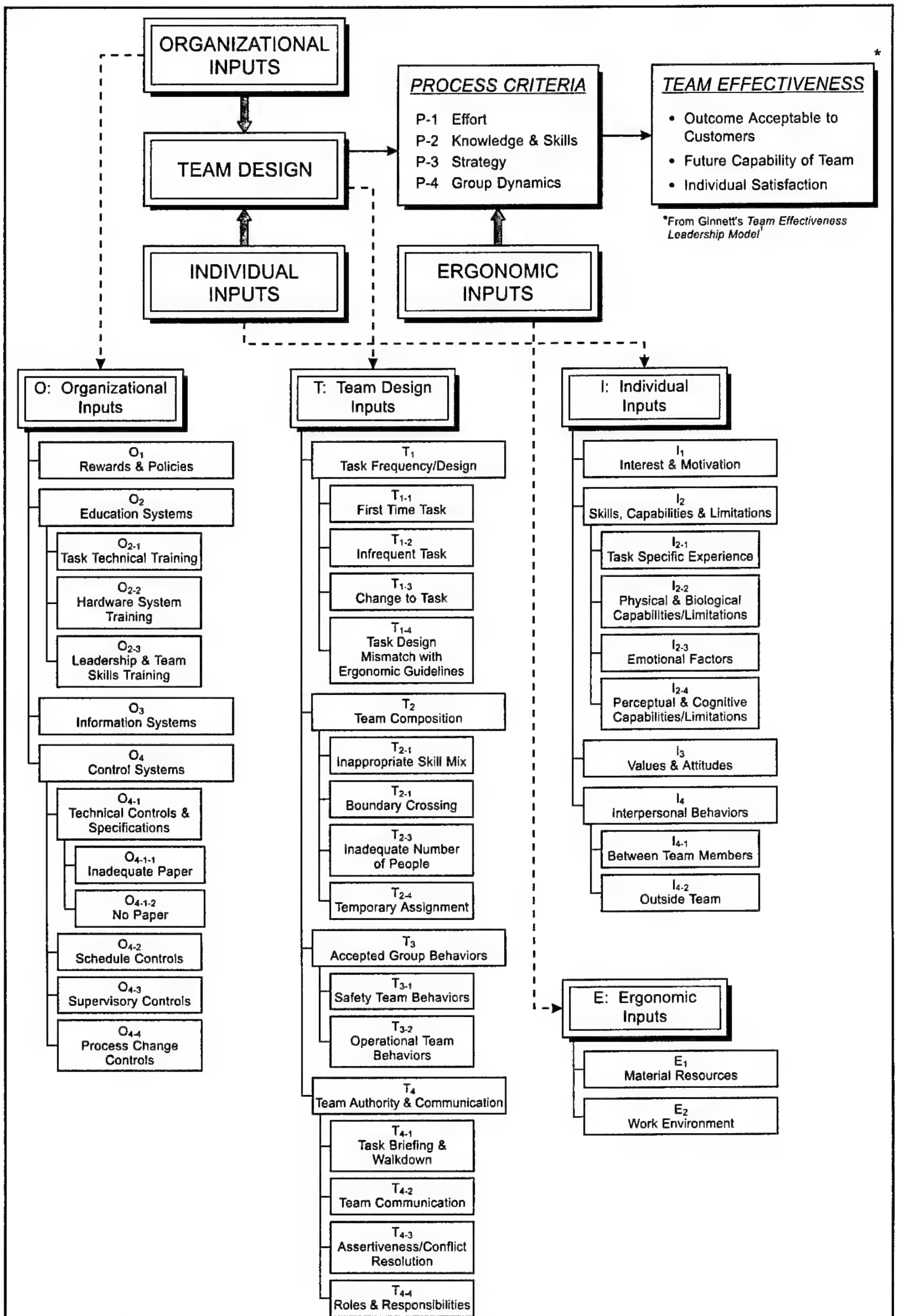
KSC's Human Factors team developed the Human Factors Event Evaluation model by studying various human factors data-gathering methodologies; and previous research. Studies included those by the Center for Creative Leadership/NASA Ames Research Center, ongoing incident investigations at KSC, and the results of research performed from the Summers of 1992 through 1994 at KSC by NASA Ames and the U.S. Air Force Academy's Department of Behavioral Sciences. The KSC Human Factors team then modified the Team Effectiveness Leadership model, developed by Dr. Robert C. Ginnett, by expanding and customizing its compatibility with the Shuttle Processing Operations (Figure 2-7). By using the model, the team reanalyzed 25 previous incidents and was able to test both the validity of the model, as well as identify valuable, additional root cause data. The data produced through application of the model is stored in a Microsoft Access database.

The Human Factors Event Evaluation model provides greater understanding of the interrelationship between humans and processes, new insights into root causes contributing to errors, and better capability for analyzing trends. The Human Factors team educates KSC personnel on human factors issues through newsletters, training sessions, seminars, and workshops. By providing an understanding and analysis of human factors, the team strives to reduce incident occurrences across all operations at KSC. The Human Factors Event Evaluation model also provides valuable documentation on the human factors element and its effects on Shuttle Processing Operations. The model has much potential and could easily be applied to larger activities and operations at KSC and private enterprise.

## Orbiter Reliability Centered Maintenance

To support cost reduction initiatives, KSC established an Orbiter Reliability Centered Maintenance (RCM) program to reduce the required tests between orbiter flights. Previously, KSC conducted extensive tests on critical hardware between each flight based only on hardware criticality, design criteria, and some failure history. Orbiter RCM takes advantage of the information regarding the hardware's successful past performance and the previously mentioned criteria and incorporates these into the testing program. Since most avionics and electrical component failures result from ground power time and not flight operational time, conclusions implied the failures occurred from extensive testing between flights and not from normal usage.

Only about 11% of today's components respond favorably to regularly-scheduled maintenance. Advanced electronic equipment does not display age degradation nor do existing tests effectively show impending failure. This has led to maintenance




[1]Hughes, R.L., Ginnett, R.C., & Curphy, G.J. (1996). Leadership: *Enhancing the Lessons of Experience* (pp. 354-366). Chicago: Irwin.

***Figure 2-7. KSC Human Factors Event Evaluation Model***

systems based on analyzing those factors which affect reliability. KSC chose the RCM methodology because of its proven track record with airline maintenance requirements. Johnson Control World Services, Inc. developed the recommendations for the initial system. Since several years of flight data was available, the baselining section of the traditional RCM approach was disregarded. The system handles fleet-reliability monitoring by comparing actual orbiter primary and subsystem performance to statistically derived control limits. When a trend rate moves outside the upper or lower control limits, action must be taken to identify the root cause and to apply the appropriate corrective measures.

Implementation of the pilot RCM system reduced the number of tests required and produced significant cost avoidance. KSC realized these benefits prior to transferring the RCM system to its process owners for full-scale use.

## Propellant Handler's Ensemble

The handling of hazardous material demands safety measures. KSC led the way in improving the propellant handler's ensemble into the safest, most-reliable garment for protecting individuals who handle hazardous material. These improvements include making the suit from a multi-layer fabric of different colors instead of a single layer, allowing for easier wear inspection; increasing the thickness of the butyl rubber which coats the suit, allowing for added durability; connecting the gloves and boots to the main suit with a metal-locking ring, allowing a positive seal for better protection than the cuff design; making the helmet an integral part of the suit, allowing the face shield to be the only rigid part on top of the suit; and placing the vent valves in the chest area, allowing for easy access.

KSC's use of a liquid air pack should draw commercial interest. The previous method used compressed air at 2,400 psi, which lasted about 40 minutes and weighed 60 pounds. The liquid air pack operates at 150 psi, lasts over an hour, and weighs only 28 pounds. Liquid air pumped throughout the suit absorbs body heat prior to becoming a gas and gives an air-conditioning effect to the handler.

KSC's current version of the propellant handler's ensemble represents the safest, most reliable, lowest-maintenance, protective garment available today. The ensemble's high cost of $10 thousand is offset by its 15-year life span.

## Technical Documentation System

KSC uses the Technical Documentation (Tech Doc) System, an electronic management system, to generate, deliver, retrieve, process, store, and track any document necessary for Payload Processing operations. The Tech Doc configuration consists of a client-server architecture with a dedicated ALPHA™ and local personal computers.

Payload Processing uses more than 5,000 documents in its operations, representing more than 30 different types of documents. Prior to the Tech Doc system, no centralized repository for documentation existed. Document storage occurred on various platforms, ranging from the personal computer to mini-computers. No standard format or controls governed the creation of the documents and distribution consisted of hard copies. Inaccurate tracking of documentation releases, revisions, and distributions created considerable uncertainty with configuration control. Improvements to the documentation process were a necessity.

After analyzing the documentation flow, KSC identified the deficiencies of the previous method and incorporated the Tech Doc system. Word for Windows or any Native format creates the documents. Electronic Data Control System (EDCS) software handles the file management and control of the documents. EDCS Graphical User Interface runs in the MS-Windows environment and is the user-interface to EDCS on the ALPHA™. BASISPlus software provides quick document search and retrieval by using the text of a document. Document routing and reviewing are performed using EDCS and any Standard Mail Transfer Protocol. The Web Browser and Adobe Acrobat Reader provide document viewing.

Tech Doc's functions now provide templates for the creation of each document; a list of members for documentation access, notification, and distribution; electronic review and approval; document modification; tracking of every activity of the document; archiving old documents; and the release and distribution of the documents. The system performs simple searches on one data field and accommodates complex searches on two data fields by using a joined operator. Viewing can be performed at the text level or at the document attribute level. Documents can be retrieved in Native format, Postscript, or Portable Data Format.

Tech Doc streamlined KSC's document-generation procedures, reduced the documentation creation time,

and allowed revisions of a document to be performed with ease. In addition, hard copy distribution is no longer necessary.

## *Facilities*

### Aerospace Facility and System Design and Implementation

The Aerospace Facility and System Design and Implementation team provides expertise for designing, constructing, and enhancing the survivability of KSC's launch and payload processing facilities, structures and systems. This expertise guides a project from initial concept, to identification and definition of requirements, through the project development, design, and implementation, and finally to full operation. The team must maintain a balance between NASA's requirements and the state environmental regulations for protecting the surrounding wildlife refuge. It is not uncommon for mating habits or natural migration of wildlife to halt a project.

The team supports the launch structures with sound and acoustics suppression systems; specialized access and servicing platforms; lightning protection design, construction, and survivability; emergency power systems; modification and redesign of launch structures; and deluge water protection systems. In addition, the team designs hazardous and non-hazardous payload processing facilities and systems, and develops specialized, fine-motion, 350-ton cranes which are capable of moving loads at the rate of 0.040 inch per minute. These unique cranes can also support the growth of KSC's launch facilities.

The Aerospace Facility and System Design and Implementation team promotes teamwork between itself and other specialized departments such as management, technical, operational, environmental, and safety. Through this approach, KSC has succeeded in breaking down department barriers and obtaining the best working solutions.

### Fluids Management

As the leading government agency for spaceflight-propellant management, NASA's corporate knowledge base contains the most comprehensive information on propellants, gases, and specialized fluids such as chlorofluorocarbons. Other topics include industrial supply sources; manufacturing and analysis processes; storage, transportation, and handling; and supporting hardware design and development. The Department of Transportation Regulatory Agency recognizes KSC as the primary, technical expert in the area of hazardous material equipment standards.

Numerous accomplishments have resulted through KSC's fluids management programs. By using direct delivery, minimizing its supply stock, and implementing a recycle program, KSC improved its hypergol operations, reduced its production of toxic waste, and saved $120 thousand per year in new purchases. KSC also designed, developed, and procured propellant transportation vessels and ground support equipment to support all U.S. space operations. The effort produced a safer and more environmentally-sound container for toxic liquid propellants.

KSC continues to strive for improvement by benchmarking with industry. Goals include balancing government guidelines with industry standards, increasing cooperation between other government agencies and industry, and improving safety, regulatory, environmental, and economic issues.

### Mechanical Ground and Facility Systems and Equipment

The Mechanical Ground and Facilities Systems and Equipment team designs and develops mechanical systems to support the launch, landing and turnaround activities of current and future launch vehicles. In addition, the team develops, qualifies, and implements systems and equipment to meet the unique requirements of shuttle processes and future launch vehicles. Working with its customers, the team focuses on handling and umbilicals; transporters and structures; hydraulics and pneumatic; propellants and life support; mechanical engineering analysis; and mechanical component testing and qualification.

The diversity and legacy of this team enable the group to develop systems and equipment which meet KSC's unique requirements and reduce the cost of processing, checkout, launch, and landing operations. By pulling resources and expert staff from various on-site departments, the team can implement a total system integration process, from initiation to conclusion.

Competent, knowledgeable personnel promote customer trust, understanding, information exchange, and participation from other teams. Immediate analysis of potential situations protects equipment, personnel, and scheduling commitments.

When a serious problem occurs, the time and money spent on an outside consultant may be less beneficial than realized. The consultant may not possess an in-depth understanding of the entire orbiter process, or the investigation may surface another problem which does not fall within the consultant's expertise.

One success story cited by the Mechanical Ground and Facilities Systems and Equipment team dealt with a scrubbed launch due to hydrogen leakage. To help resolve the situation, KSC decided to build a prototype purge system and mock-up of the orbiter and liquid fuel tank inside the Launch Equipment Test Facility. By pulling resources and staff from various on-site departments and working round-the-clock, the team quickly assembled the system and mock-up and completed the necessary tests. The data results proved the viability and a decision was made to modify the mobile launch platform.

This dedication and in-depth understanding of the orbiter process have been documented and are traceable to the earliest launch activities at KSC. The team continues to prove itself as world-class experts in special access platforms, payload handling structures, and umbilicles propellant handling.

## Payload Operations Network and Network Control Center

Payload Operations Network (PON) currently supports more than 3,100 nodes and 1,900 users. Comprised of several local networks tied together, PON interconnects all the payload facilities into one LAN. In addition, PON provides network services and integrated information technology support for all payload civil servants and contractor personnel. A centralized Network Control Center (NCC) controls operation and maintenance of the network and provides support to users through a customer help desk.

Prior to establishing PON, isolated networks and diverse applications existed throughout KSC. Each network required its own dedicated wiring and used proprietary protocols. User areas, scattered throughout the Payload Operations facilities, housed the servers and network equipment. These networks lacked configuration control, adequate budgets, and knowledgeable support personnel. As information and network technology began to grow and mature, the demand for network availability and reliability increased. Likewise, as operations became increasingly automated, more equipment was required to support the payload facilities. To deal effectively with these changes, PON was setup and became operational in 1991.

PON consolidated the core networking equipment into one central location and installed network cabling in each office of the major payload facilities. Dedicated, support personnel operate and maintain the network. KSC developed configuration control and detailed documentation for the entire system and state-of-the-art tools and techniques for troubleshooting problems. As an advanced central facility, NCC monitors and controls the PON activities. In addition, a separate network engineering group focuses on new implementations and future designs to keep the system up-to-date with new technologies. NCC now supports its users' requirements through a stable budget and a well-managed project plan.

NCC's help desk provides immediate support for all network hardware and software problems. As the initial contact for handling potential problems, the help desk successfully solves more than 20% of the field calls without ever dispatching an analyst. The help-desk software, developed by KSC, tracks all active problems, maintains a database of previous problem resolutions, and functions as an expert system to assist help desk personnel.

NCC and PON significantly improved the network capabilities at KSC. Centralization and commonality produced immense improvements in cost, speed, and accuracy. Workgroup computing, which segments the network into smaller groups, minimizes broadcast traffic from propagating across the entire network and increases performance and available bandwidth. Internet access to the network provides customers with communication capabilities to off-site facilities. Remote connectivity allows customers to access data at off-site facilities without incurring transportation costs. The expertise and knowledge gained from developing PON and NCC are being shared internally at KSC and with other NASA centers, contractors, and government agencies.

## Preventive Maintenance

KSC has always had a very aggressive Preventive Maintenance (PM) program for its equipment, machines, and facilities. Given the corrosive environment of the Florida region and the stringent requirements for safety in all of NASA operations,

KSC performed most of its PM based upon fixed-time repetitive procedures. However, using time or operating hours as a basis for maintenance does not take into consideration any failure mode analysis derived from historical data gathered.

Starting in 1992, KSC initiated a Predictive Maintenance (PDM) pilot program to take advantage of the available technologies for analyzing and quantifying the conditions of its equipment and facilities. Available PDM technologies include:

- Vibration analysis for balance analysis of rotating machinery
- Ferrography for wear particle analysis of machinery lubricants
- Thermography for infrared thermal imaging of electrical and mechanical systems
- Ultrasound for ultrasonic leak detection
- Ultrasonic non-destructive evaluation for material degradation detection
- Laser alignment for maintaining peak rotational alignment

Through PDM technologies, KSC started predicting the condition of its equipment, facilities, and future failure modes. Early detection of system hardware problems now makes it possible for required maintenance to be performed.

In 1994, KSC combined the PM and PDM programs into one maintenance management philosophy. By using proactive maintenance processes and incorporating the PDM technologies and PM practices, equipment life-cycle costs were minimized. The approach, referred to as the Reliability Centered Maintenance (RCM) process, allows KSC to increase equipment and facilities up-time from 77.1% to 98.1%. In addition, KSC realized cost savings of more than 12,000 man-hours in FY94 (the first year of implementation). Since implementation, corresponding cost savings have been generated in out-years. Future plans call for evolving RCM into the root cause analysis as the next stage of proactive maintenance.

## Rack Insertion Device

Most shuttle payloads are carried on/in specialized racks which are hard-mounted to a floor system and installed inside the module (floor and ceiling areas) of the space laboratory. With a space station possible in the near future, the increased demand for payloads would require a labor-intensive operation to install the 2,000-pound racks into the module. First, specialized, high-capacity floor systems would have to be installed inside the module. Then floor-mounted jacks would position the racks prior to hard-mounting them onto the floor systems. The space occupied by the floor system and jacks would prevent the accommodation of floor and ceiling racks. Afterward, another labor-intensive operation would be needed to remove the floor systems, jacks, and other ground support equipment. Excessive handling and manipulation would also present an increased risk to the racks and associated payloads.

To improve operations, minimize damage to the payload, and maximize module capacity, KSC designed a specialized Rack Insertion Device (RID). This device, a multi-axis manipulator, supports rack installation from the floor outside of the module (Figure 2-8). The manipulator positions the racks into the module within 0.015 inch of its predetermined position. With this device, fully-loaded racks are installed into the module without using flooring systems, jacks, or specialized ground support equipment. Payload per module increases because RID accesses all areas of the module's floor and ceiling by using the 5-axis degrees of freedom

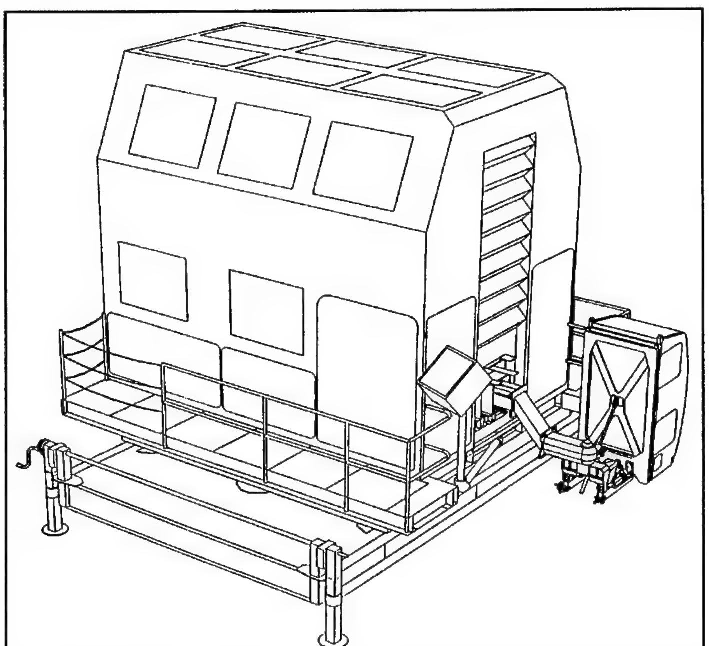


***Figure 2-8. Rack Insertion Device***

and rotation. Figure 2-9 shows the fully-extended manipulator arm as it positions and installs a rack in a typical module.

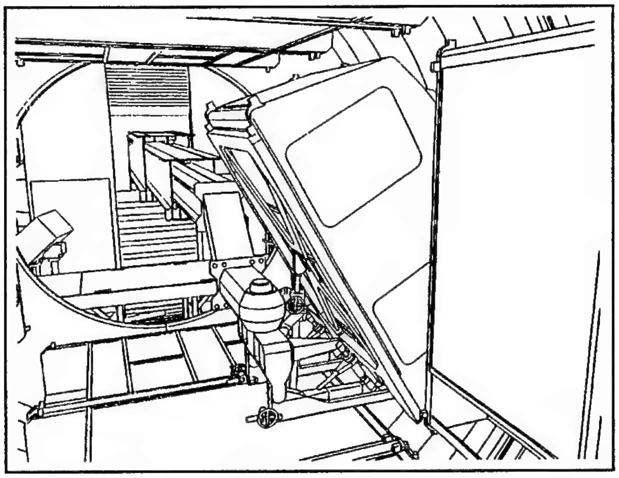


***Figure 2-9. Rack Installation***

RIDs eliminate the need for tilt pallets and center of gravity (CG) tables, reduce manpower requirements for rack installation, and shorten the leadtime for preparing modules for flight. KSC has already realized a $1.5 million savings in cost avoidance. Testing to this point indicates the actual-operation savings may be even greater than expected. Rack-operation savings are presently estimated at over $1 million.

## *Logistics*

### Expert Learning for Vehicle Instruction by Simulation

KSC maintains its corporate knowledge from the past 30 years through formal classroom training, mentoring, actual-shop-floor training, and on-the-job training. To supplement its training methods, KSC began developing simulation programs. One of the most effective and successful programs is the Expert Learning for Vehicle Instruction by Simulation (ELVIS).

ELVIS improved the training method for the shuttle hardware engineers who are responsible for vehicle subsystems support. The engineers gain knowledge and familiarity of the individual operation procedures through a simulated test environment. ELVIS repeats the test and procedures as often as the engineer deems necessary. This familiarization helps to ensure procedure compliance and reductions in testing and processing times. Safety and reliability of shuttle operations are also major benefits of this electronic-training tool.

Started in Fall 1993, ELVIS evolved over three years into a completely-integrated, high-fidelity, interactive, training tool which models the orbiter systems and ground support equipment. ELVIS provides the necessary, procedural training to ensure safe and reliable operational tests; displays the interfaces which would normally be encountered during tests and processing operations; and furnishes advisory notes to indicate possible causes of a procedural error. No control room resources are necessary for this training. ELVIS supplies the user with hands-on instructions in a Launch Processing System environment, provides an on-line help facility on the Internet of the KSC facility, and is gaining new users on a daily basis.

### Space Shuttle Logistics Management

The Logistical Operations Directorate assumed responsibility for space shuttle orbiter logistics management and operation functions in FY87. In addition to providing replacement hardware for the Space Shuttle Program (SSP), the Directorate furnishes logistical services such as original equipment manufacturer (OEM) management, failure analysis, repair depot operation, and supportability analysis.

Overwhelming best describes the SSP logistical task in magnitude and complexity. More than 250,000 part numbers exist for each orbiter and related ground support equipment. This involves the installment of over one million parts because of the multiple duplication of some parts. While KSC provisions over 55,000 of the part numbers, an additional 9,000 are handled for repair. Spares must be maintained for everything, from washers through fuel cells for four orbiters, to over 300 ground support end items. In addition to the large scale job of procuring, warehousing, and distributing new spares, KSC must monitor 52 repair agreements with major subcontractors, manage the NASA Shuttle Logistics Depot (NSLD), and locate new sources for parts which are no longer available from the original suppliers.

To handle this enormous job, KSC uses numerous management methodologies to supplement its extensive base of knowledge on reusable spaceflight logistics. In addition to applying sound business practices, KSC developed unique databases

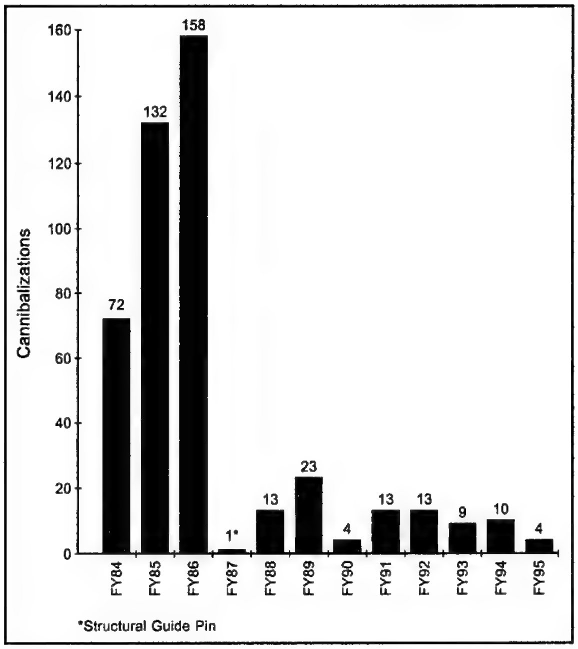



***Figure 2-10. Orbiter Program Cannibalizations***

for the logistical processes and discrete simulation models to assess the status of critical spares and support maintainability. Priorities and performance measures improved the efficiency of the NSLD activities and dictated direct (to subcontractor) procurement methods.

Since assuming these responsibilities, the Logistical Operations Directorate has documented significant achievements. The cannibalization rate of the SSP logistical support program dropped from an average of 120 cannibalizations per year to 8 per year (Figure 2-10). KSC's ability to furnish spares from on-hand supplies rose from 90% to 98% (Figure 2-11). Overall supportability performance (Figure 2-12) for on-time spare delivery

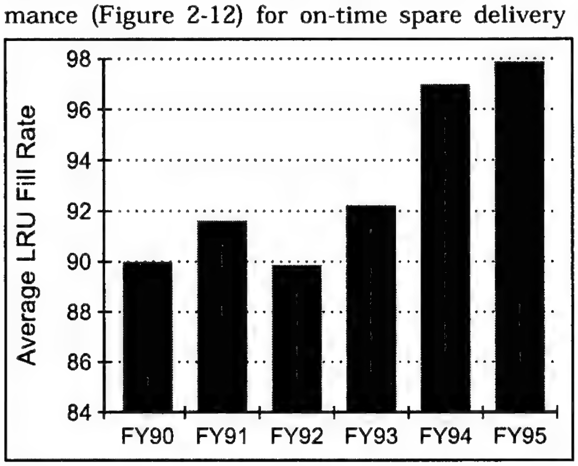



***Figure 2-11. Provisioned Line Replaceble Unit Fill Rate***

grew to over 99% in FY95, and the requirement for cannibalization became almost nonexistent. While reducing program costs, the Directorate effectively managed the loss and transition of numerous OEMs through the development of equivalent repair, manufacture, and failure analysis capabilities at the NSLD. In addition, KSC eliminated essentially all of the Capability Retention Contracts (industry contracts are maintained solely to retain unique capabilities).

KSC also developed a Failure Analysis Capabilities Matrix which provides customers with expertise from various facilities on failure analysis capabilities that exist within the Space Shuttle Program.

The current matrix concentrates on the facilities located at KSC, Cape Canaveral Air Station, Rockwell Downey, and the Government Depots (NSLD and White Sands Test Facility). The matrix is divided into three sections (capabilities and equipment; specialized test facilities; and site information) and lists a point-of-contact for each facility. KSC expects to augment the value of the matrix by adding more failure analysis facilities in the future.

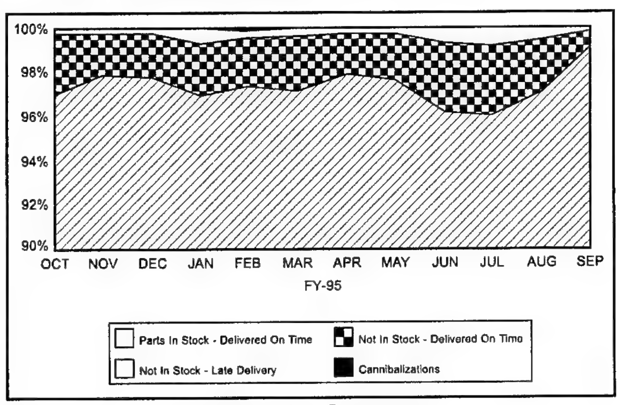



***Figure 2-12. Performance Summary***

## Spares Simulation

The Space Shuttle Program has traditionally used probability of sufficiency (POS) to determine the number of spares required for line replacement units (LRU). However, the POS calculation does not always provide adequate information regarding the risk of not having a spare LRU when it is required.

By collecting data on the actual uses and maintenance records of shuttle components, a joint Logistics and Industrial Engineering team developed a discrete event process simulation to supplement the POS method. This simulation minimizes the subjectivity in determining the spares requirements and effectively models the variability in

repair turnaround times and mean time between failures or removals for maintenance. Successfully implemented for Orbiter Auxiliary Power Units (APUs), this simulation is now being applied to the orbiter fuel cell spares process.

The spares simulation helped KSC determine whether additional APUs should be upgraded to increase the time before scheduled maintenance is required. By using the generic spares model of the simulation, an APU spares model was built. The model tested the following hypotheses: reduced repair time increases availability, increased APU reliability increases availability, and increased time between maintenance activities increases availability. Model inputs included maintenance times, failure rate, number of orbiters, total APU inventory, and APU possible locations. Model outputs included average shelf quantity, number of zero balance times, percentage of time when cannibalization opportunities exist, and duration of zero balance on the shelf. The conclusion supported the decision against upgrading additional APUs, resulting in a cost avoidance of up to $14.7 million.

## *Management*

### Advanced Technology Programs

To improve the coordination and effectiveness of its services, KSC consolidated its five technology transfer-related activities into a single Technology Programs and Commercialization Office (TPCO). These five activities consist of advanced technology development; technology transfer and commercialization; patent and other intellectual property protection; small business development; and university technology programs. Consolidated activities within the TPCO enable KSC to enrich its industry partnerships, extensively leverage its resources, and maximize its dual-use developments. The result is a superior system for new technology development which maximizes the positive relationships between commercial equipment developers, university researchers, and potential users of KSC technologies.

Under this system, advanced technology development starts with the first-line directors prioritizing KSC's current technology needs. Next, the TPCO conducts a market analysis to determine potential commercial involvement in the development of each technology and examines its background for prior-NASA intellectual property which requires protection prior to public release. Release of an Announcement of Opportunity (AO) describes the desired technology development to potential industry partners. Following this, KSC holds information briefings for interested companies, solicits commercialization plans (including co-funding proposals), selects the best industry partner(s), and signs a partnership agreement(s).

Since most companies propose dual-use developments with shared development costs, the cost to NASA for these closely-monitored technology developments averages only one-third of the total development costs. Figure 2-13 illustrates an example of such a development, a two-phase cryogenic flowmeter developed by Air Products, where NASA's share of the development costs represented 20%. This illustrates clearly the win-win results of this program in which NASA obtains needed technologies at reduced costs, and industry acquires new products. In addition, the consolidation of the functions within the TPCO permits KSC the flexibility to place each developed technology within a spectrum of possibilities. For example, a NASA-developed technology under consideration through its spin-off promotion could instead be the focus of an AO solicitation, if the TPCO determines the technology will result in improved commercialization.

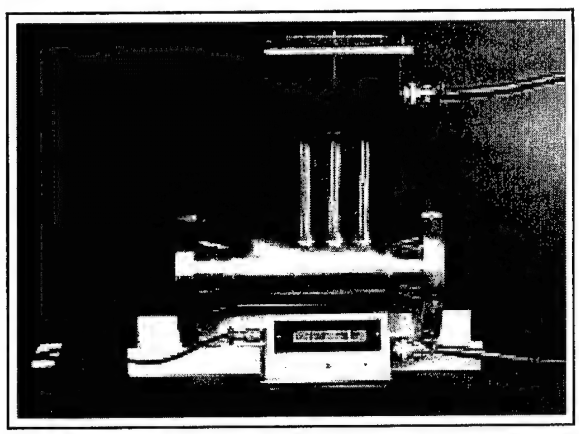


*Figure 2-13. Two-Phase Cryogenic Flowmeter*

Another feature of the TPCO is its aggressive effort to support regional, economic development needs. These efforts include a business development incubator developed in partnership with a local community college and the State of Florida; an Internet-based marketing program for NASA-developed technologies to provide easy business access; and a technology outreach program to transfer the expertise of KSC to the regional business community by providing solutions to technical problems typically encountered by such businesses.

This latter effort, marketed in Florida by county economic-development organizations, enables businesses to benefit from KSC experience and expertise without any cost to the business. The ease by which a business may access this service is enhanced by the simple, straightforward Technology Transfer Agreement form developed by the TPCO for use by companies requesting this assistance.

## Benchmarking

Over the years, KSC implemented a benchmarking function to gather data on internal KSC facilities, teams, and organizations. However, this capability quickly evolved into a more formal operation which now conducts external studies for common interest groups and primary KSC processes. Table 2-1 provides examples of both internal and external benchmarking studies conducted by KSC.

KSC established a Benchmarking Network in collaboration with nine major support contractors and pioneered consortium benchmarking techniques to reduce the cost of benchmarking studies. As process changes are implemented, various KSC organizations are reporting benefits from the benchmarking activities. For example, a government property management study produced $41 thousand in cost avoidance from three organizations within two months of the release of the preliminary findings. Several organizations also reported significant cost avoidance and reductions in property loss reports. As a result of these successes, NASA designated KSC as the leader in agency benchmarking. In addition, the KSC Benchmarking Network has received recognition through various sources such as the 1995 Silver Medal Benchmarking Award in Applied Research from the International Benchmarking Clearinghouse.

***Table 2-1. Examples of KSC Benchmarking Studies***

| PROCESS/STUDY | PARTNERS | TYPE OF STUDY | SCOPE OF STUDY | RESULTS |
|---|---|---|---|---|
| Government Property Management | KSC Benchmarking Network Members | Formal | Internal | Reduced Cost & Cycle Time, Improved Quality |
| Facility Maintenance | NASA Centers & Industry | Formal | External | Reduced Cost & Improved Quality |
| Software Development | Software Engineering Institute | Formal | External | Reduced Cycle Time & Improved Quality |
| Facility Reliability-Centered Maintenance | NASA Centers & Industry | Formal | External | Reduced Cost & Improved Quality |
| Standard Wear | Depot-Level Maintenance Organizations | Formal | External | Results in Work |
| Welding | Shuttle Processing Facilities | Formal | Internal | Results in Work |
| Ground Support Equipment Scheduling | Shuttle Processing Facilities | Formal | Internal | Study in Work |
| Case Tracking & Management | Selected Law Firms | Informal | External | Reduced Cycle Time |
| Launch Processing | China, Russia, Japan, Arianespace | Informal | External | Data for Strategic Planning |
| Orbiter Processing Performance | Different KSC Facilities & Shuttle Missions | Informal | Internal | Reduced Cost & Cycle Time, Improved Quality |
| Special Material Inventory & Tracking System | DoD & Industry | Informal | External | Improved Control & Accountability |
| Areas of Excellence | Shuttle Processing Facilities & Groups | Informal | Internal | Improved Quality |

In general, KSC determines the amount of resources to invest by estimating the potential return on the investment and by considering the criticality of the process, the process stability, the availability of documentation, and the cost of implementing process changes. Benchmarking techniques, however, are subject to continuous improvement through customer feedback, new technology availability, and the evaluation of improvements and lessons learned from previous studies.

## Customer Payload Processing Operations

KSC serves as host to numerous payload customers by providing facilities and services for payload final assembly and launch preparations. A close-working relationship between KSC and the customer develops prior to hardware arrival. Based on detailed knowledge from the customer, KSC plans, schedules, and tailors its support products and services to the specific launch site requirements. Additional support includes educating the customer about the myriad of requirements for integrating the payload into the shuttle system.

A Launch Site Support Manager (LSSM), designated for each payload, works with the customer to ensure the customer's needs are being met. Responsibilities include assisting the customer with the daily schedule, committing necessary KSC resources to the customer's payload, identifying optional services for test and support requirements, and maintaining funding support through either NASA Headquarters or the payload project.

With more pressure for NASA to accomplish its tasks faster, better, and cheaper, the LSSM's role has taken on greater importance and requires increasingly earlier involvement in the planning

process. As much as two years before a scheduled mission launch date, the LSSM assists in the payload design reviews and begins working with the customer. KSC also implemented new processes to streamline its procedures and provide information resources for its customers. Payload Operations and Launch Site Support Office websites have been set up as communications resources to provide information handbooks, payload customer guides, safety documentation, generic schedules and processing flows, and key points-of-contact. Launch Site Support Planning requirements now are more focused and simpler, and use shorter development templates. New metrics measure customer satisfaction levels to determine whether KSC is fulfilling the customer payload processing requirements.

All these improvements reflect KSC's commitment to its customers. By focusing on early and continual involvement with the customer throughout all phases of the payload integration process, KSC obtained an in-depth understanding of its customer needs. Through this approach, KSC continues to improve all aspects of the payload processing for its customers.

## Customer Survey Process

KSC's strong commitment to customer satisfaction drives its personnel to constantly search for new and innovative ways to increase the satisfaction levels of its payload services. Prior to recent changes in the methodology of conducting customer surveys, the traditional approach of obtaining customer satisfaction information consisted of mailing out a questionnaire, reviewing the comments upon return, tallying up a score rating, and getting back to the customer on major concerns. This process provided low feedback rates to KSC because customers viewed the approach as antiquated, complicated and reactive.

Key changes include simplifying the questionnaires with short essays, installing suggestion boxes in the payload processing facilities, and involving the customer (survey team) and the LSSM in the survey process. Immediately after completion of a service, the LSSM interviews the customer, fills out the simplified questionnaire, returns the form to the customer survey team, and participates in discussing customer comments with the mission processing teams at KSC. The formal process addresses any customer concerns immediately, while the LSSM provides the customer with a final mission report and discusses concerns or suggestions with the customer on improving service.

Since implementing this process, survey responses increased from 75% (with a 50% incomplete or inaccurate rate) to 100%. Other benefits include higher quality input from the surveys, quicker turnaround times of the process, and improved relations between the customer and the LSSM on customer satisfaction issues.

Customer follow-up is imperative to customer satisfaction. By involving the customer and maintaining a flexibility in the data collection process, KSC proved that survey responses and satisfaction levels can increase. The customer survey process is an ongoing initiative that must be continually improved in order to fit the needs of a changing environment.

## Interactive Task Execution Program

To ensure a customer's needs and requirements are being met, the KSC Weather Office implemented the Interactive Task Execution program. This program enables the customer and the tasked organization to work together throughout the cycle of a requested task. At the start, both sides meet to discuss the preliminary steps needed to fulfill the task. From this discussion, the tasked organization develops a proposed strategy which must be approved by the customer. Each month, the task organization keeps the customer informed on the status of the task. In addition, the customer evaluates the task and any revisions at all critical milestones. E-mail and teleconferencing keep the information costs at a minimum.

Upon completion of the task, sample products are submitted to the customer and an independent expert for review before the final product is prepared. Even after delivery of the final product, the tasked organization follows up on the customer's satisfaction and addresses any problems at that time. Benefits of the Interactive Task Execution program include improved communication between the customer and the tasked organization, successful matching of solutions to task requirements, higher quality products with fewer errors, increased customer satisfaction, and increased usage of the product by the customer.

## Lightning Safety

The KSC Lightning Safety Assessment Committee is responsible for protecting the launch pads, assembly buildings, hazardous fuel and energetics staging and assembly areas, orbiters, and payloads from lightning strikes. Throughout the KSC complex, various types of lightning conductors are positioned. These include elevated wire grids around buildings; unique, catenary wire assemblies at the launch pads; and standard lightning rod assemblies. Despite 13 direct strikes on the launch pads with spacecraft present (Figure 2-14), these lightning conductors have protected KSC spacecraft assemblies and payloads from potential damage.

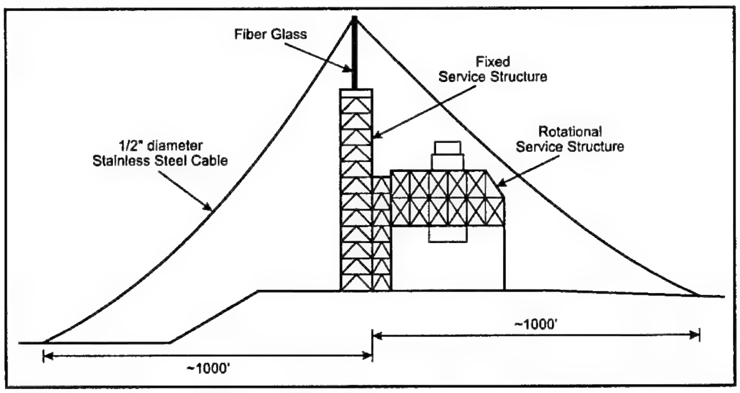



***Figure 2-14. Protective Wire System***

I-Net, a KSC contractor, has created the newest technology for lightning safety. Known as a "shoebox", this small, portable device measures the maximum magnetic field, the waveform, and the rise rate of current. During the Summer of 1996, KSC installed a "shoebox" at each launch pad. The devices, however, can be used in other applications where lightning characteristics are important for designing or providing protection of sensitive electronics and energetics.

## Manifest and Facility Planning

KSC employs a dynamic, multiflow-assessment mechanism to track critical resources across multiple processing flows and determine if planned payload processing can be performed with available resources in a given time frame. The process yields optimal facility utilization plans, manpower plans, flight hardware utilization, and ground support equipment utilization.

Previously, no standard format existed for establishing a resource plan for new payloads. Best estimates were used to determine whether facilities, manpower, flight hardware, and ground support equipment would be available for required time frames. Based on current manifest, resource plans emerged as handwritten or computer-generated charts. Cumbersome data collection, analysis, and revision methods required considerable manpower. Negotiation handled conflicts, but priorities were difficult to defend. As a result, payload processing costs and schedules suffered under this practice.

Over the years, changes directed NASA to reduce its facilities and resources, but maintain its highly-reliable payload process. Diligent scheduling practices required maximum efficiencies from the KSC resources for supporting payload requirements. In addition, manifesting is an iterative, dynamic function which affects multiflow and facility utilization planning.

In response to these challenges, KSC implemented a new Manifest and Facility Planning practice. The practice used a multiflow-assessment mechanism to track critical resources across multiple processing flows and determine if planned payloads processing could be performed with available resources. Development of facility capabilities and capacities, payload requirements, and standard flow databases allow KSC to maintain current and viable data for use during the planning process. True payload requirements generate strategies for assigning payloads in the processing facilities. Assignment strategies minimize major scheduling problems, prioritize the process, and identify limiting resources. A COTS scheduling program simplifies manifest changes for revising plans and provides information on facility, manpower, flight hardware and ground support equipment.

Manifest and Facility Planning provides a comprehensive analysis of the major factors which affect the outcome of long range planning, identifies resource conflicts, validates planned hardware availability, performs theoretical assessments, and assists in budget projections. Automation of the process reduced the labor for data processing and increased the accuracy of the multiflow-assessment mechanism. KSC uses the Manifest and Facility Planning practice on current payloads and the International Space Station program.

## Negotiated Tasking

The KSC Weather Office improved its management, operations, and effectiveness of environmental responsibilities by devising negotiated tasking with its key organizations. In the past, the various key organizations operated in an isolated and self-regarding manner. This rationale resulted in duplication of effort, dilution of scarce resources, and poor communications with the Weather Office. Over time, the Weather Office succeeded in promoting cooperation between the key organizations through negotiated tasking. Negotiated tasking, based on communications and the sharing of resources, responsibilities, and results, proved to be a simple, straight-forward and highly effective process.

The negotiated tasking process begins by calling a meeting of the key organizations, which includes any interested or expert members. To reduce meeting time and costs, e-mail and teleconferencing methods are employed where possible. Discussions cover such topics as defining and meeting requirements, trade-offs, solution costs, potential division of labor, and support sources. Once the goal of consensus is attained, the organizations obtain the appropriate levels of management approval. Any revision to the original consensus requires the group to reconvene and establish a new consensus.

Benefits of the negotiated tasking process include aggregating, leveraging, and focusing resources on the highest priority; capitalizing on each organization's best talents; free and open exchange of information between organizations; and cooperation and consensus by all members. The Applied Meteorology Unit (AMU) tasking process best demonstrates the effectiveness of negotiated tasking.

## Payload Ground Safety Review Process

KSC established its ground safety policy requirements for payloads, experiments, and support equipment through its Shuttle and International Space Station (ISS) Program Offices. These requirements protect flight and ground personnel, orbiters, ISS, payloads, support equipment, property, the public, and the environment from payload-related hazards. To assist payload customers in implementing these safety requirements, KSC established a Ground Safety Review Process (GSRP). The GSRP staff manages the Ground Safety Review Panel and gives the final safety approval for payloads to begin ground processing at KSC.

The GSRP uses a phased approach and a scheduling process. The phased approach is flexible and generally relates to Payload Preliminary Design Review, Critical Design Review, and Design Certification Review/Payload or Ground Support Equipment Fabrication. The scheduling process mandates the customer to submit a Safety Design Package to the Ground Safety Review Panel 45 days before it convenes. The Safety Compliance Data Package must include descriptions of the intended ground operations at KSC; the flight hardware (payload) being processed including all hazards, interfaces, testing, servicing, lifting, transporting, and integrating; and the support equipment with its schematics, design information, matrices and other relevant data.

The Ground Safety Review Panel assesses the Safety Compliance Data Package, evaluates all identified hazards and acceptable controls; negotiates resolution of payload ground safety issues; interprets launch and landing site safety requirements; and evaluates non-compliance reports. KSC encourages its customers to communicate early and frequently with the Ground Safety Review Panel to ensure all safety requirements are met. In addition, the panel performs joint research with its customers to establish safety standards for new technology, such as nickel hydrogen batteries and composite overwrapped epoxy pressure vessels.

The Ground Safety Review Panel responds to its customer's needs without compromising safety. No fatalities or payload losses have occurred during payload ground processing operations at KSC. The panel constantly strives to work in cooperation with its customers to improve its methods, learn from its experiences, and adjust the review process as needed to ensure safety. Recognized as a leader in ground safety requirements, KSC frequently assists inquiring customers with safety requirements or safety operation issues at their own facilities.

KSC continues to streamline and improve the procedures of the GSRP. Improvements include conducting most reviews by mail or telephone to reduce travel time and costs, and replacing safety design analysis with COTS equipment. In addition, ISS program realized a $10 million savings by implementing an In-line and Phase Ground Safety Process for its ISS flight hardware.

## Safety Policies and Requirements

KSC's Safety Directorate represents one of the few organizations in the world which fully understands the mandated safety requirements and processes needed to ensure the safe launch and recovery of space vehicles. Because of the complexity involved in launching manned spacecraft and payloads into space, KSC developed and implemented special safety procedures to deal with the hazardous operations and materials used. First published in 1979 to support the shuttle program, the Ground Operations Safety Plan, GP-1098, contains all the safety policies, procedures, and requirements followed by KSC. The publication consists of two volumes which are continually refined as the program moves forward.

The GP-1098 addresses each type of hazardous operation by definition, specific resource information, and step-by-step instructions required to perform the operation safely. Each hazardous step requires a verification by on-site or Firing Room safety personnel before the operation can progress. Any deviation to GP-1098 requires a detailed risk assessment and concurrence by the Director of Safety at KSC.

After every launch and landing, a post-test debriefing occurs to address in detail any issues on safety, operations, and engineering, and to assign corrective action. Lessons learned from these operations are incorporated into the GP-1098 where appropriate. In addition, all KSC employees must report any event that results in personal injury or damage to equipment. These events are categorized into specific types depending on the severity of the injury or the value of the equipment. Serious events require the establishment of an accident investigation board to determine the cause of the incident so that corrective actions can be taken to reduce the risk of recurrence.

The Safety Directorate has established an excellent safety record over the past 30 years of launching and recovering spacecrafts. By capitalizing on this experience, the detailed safety requirements and procedures are constantly enhanced and improved. In addition, changes in the technologies that support these operations are recognized and incorporated where appropriate.

## Tech/QC Computer Based Training

A Shop Floor Control/Data Collection (SFC/DC) system was installed at KSC to collect data, define areas of potential improvement, and justify process changes in shuttle processing facilities. The SFC/DC system necessitated the Tech/QC Computer Based Training (CBT) tutoring approach. Although KSC technicians received instructions on how to use the SFC/DC system, the previous training failed to identify the benefits gained from the system or the importance of entering accurate data. The CBT tutorial was designed to overcome these training inadequacies. In addition, it increased awareness among the users, whose processes are being measured in the SFC/DC system, on the perspectives of the technicians responsible for entering the data.

The CBT tutorial, developed with a COTS authoring system for delivery over a LAN, acted as the pathfinder in the Orbiter Processing Facilities for additional just-in-time, computer-based training modules for technicians and quality inspectors. Features of the tutorial include flexible user interface; remediation capability during training exercises; and automated tutorial evaluation. Benefits from the Tech/QC Computer Based Training include labor savings from reduced training time, fewer conflicts with processing schedules, improved training consistency, and readily-available refresher training.

## Weather Support

As a world-class operation, the KSC Weather Office deals on a daily basis with many issues which govern the launch and recovery of manned spacecraft and all surrounding ground operations. Spacecraft operations are extremely weather sensitive, and failure is not an option. Extensive and detailed weather support must be maintained because lack of weather knowledge could lead to expensive delays and postponements or to catastrophic accidents.

The weather requirements come from multiple sources, such as the Vehicle Systems Program Office, the Range (especially Range Safety), and the Payload Systems Program Offices. Approximately 11 different sources generate the operating resources. The challenge of weather forecasting in the Cape Canaveral area is complicated by two rivers, an ocean, a gulf, being the lightning center of the U.S., the jet stream, and almost no sensors to the east. KSC constantly strives for continuous improvement in evaluating and implementing the rapidly changing weather technology, changing requirements, and changes in available resources.

The KSC Weather Office functions as a unifying force for:

- centralized coordination of all weather infrastructure projects and direct oversight of KSC components,
- operation of the AMU,
- centralized coordination of the weather-related launch commitment criteria for all vehicles and ground support operations,
- preparing and following up on weather emergencies,
- expert technical assistance to NASA, the U.S. Air Force, the National Weather Service, and contractors on weather-related issues, and
- direct control of the entire KSC weather support budget regardless of Directorate or source of funding.

The Weather Office uses a multi-agency infrastructure composed of wind towers; field mills; various sondes and spheres; 50 and 915 MHZ radar wind profiles; weather radar; lightning detection equipment and algorithms; data acquisition and display systems; and hazard models. The Weather Office orchestrates a complex and diverse array of organizations, technologies, requirements, and resources which benefit the entire U.S. Space Program and the Nation at large. Of necessity, the Office also developed and refined some of the most efficient, best management practices. KSC makes all the expertise from the Weather Office available for sharing with both the public and private sectors.

# Section 3

# *Information*

## *Test*

### Checkout, Control, and Data Systems

The Checkout, Control, and Data Systems group provides state-of-the-art, highly reliable, cost-effective, total system development to KSC for the checkout, launch, and landing activities of space vehicles' and payloads' processing and integration. Numerous programs now involve the customers throughout the development cycle.

Previously, formal review cycles occurred at six-month intervals and informal reviews occurred in real-time throughout the design and development cycles. However, misunderstandings between designers and customers could result in development downtimes. The new procedure formally involves the customer at frequent intervals during the process phase. This philosophical change decreased cycle times for the design process and reduced overall program costs.

During the planning processes, various metrics evolved and provided KSC with excellent feedback for problem solving, especially in earned value, defect density, program reporting, and customer satisfaction. Based on the metrics feedback, the overall process is well-structured but variable.

By implementing customer involvement throughout the life cycle of the design and establishing controlled processes in each life cycle phase, KSC improved its program reliability and has met its customers' requirements more efficiently. Metrics which define a program's development cycle have proven to be a valuable tool in determining process improvements.

## *Production*

### Integrated Work Control System

KSC's Integrated Work Control System (IWCS), a computer-based system, consists of four major components which tie together the key elements of the shuttle processing activities and permit the sharing of related, common data through a centralized database. The four components are Work Preparation Support System (WPSS); Computer Aided Scheduling and Planning Resources (CASPR); Shop Floor Control (SFC); and Automated Requirements Management System (ARMS).

WPSS provides an automated process for creating and managing consistent work instructions and related data for use by the Shop Floor. CASPR furnishes the necessary process management tools to support the scheduling, planning and resource-availability functions. SFC handles the work release and execution functions, and also the tracking and location of related resources used for processing the assigned Shop Floor jobs. SFC also serves as a historical reference for future work. ARMS controls the electronic support needed for the closed-loop accounting of Operations and Maintenance Requirements and Specifications (OMRS), as well as the initiation and tracking of all non-conformances.

Together these four components allow the engineer to electronically transfer work instructions to a master scheduling system, while simultaneously sending a notification about upcoming parts and material needs to the Shop Floor. Resource requirements for work startup are verified while physical locations are provided for kitting and prestaging. The actual tracking and non-conformance of work in process occur in real time. OMRS communicates the closure information to the engineer, the program, and NASA in a consistent and timely manner.

The benefits of IWCS cover a wide variety of processes from requirements notification and tracking in the program office through the execution and closure of work assignments on the Shop Floor. Increases in both efficiency and effectiveness of shuttle processing are being realized through the use of IWCS.

### Process Analysis Overview

Through KSC, various process owners maintain individual process operations for the shuttle program. To improve the overall efficiency of these operations, KSC industrial engineers began offering process analysis services to the process owners. With this approach, the process owners and industrial engineers work together to measure, develop, and implement process improvements to the individual process operations. As this approach became

more apparent through successful process improvements, more process owners began requesting the KSC services. Services developed with the KSC process analysis and industrial engineering services include spares simulation, tech/QC computer based training, benchmarking, orbiter reliability centered maintenance, human factors event evaluation model, and ground processing scheduling system.

Current projections indicate that shuttle operations will continue into the 21st century and future NASA programs will demand more complicated operational phases. Because of KSC's unique role and accumulated experience, process analysis services will remain an important tool for improving KSC's capabilities for the future.

## Structured Surveillance

Early programs at KSC, such as Mercury, Gemini, and Apollo, involved 100% inspection of all flight hardware and systems by both the contractor and NASA. This total involvement of quality in-flight hardware carried over into the early shuttle flights. Based on past experience, KSC initiated a Quality Planning and Requirements Document (QPRD) to identify inspection requirements for its shuttle program. This approach resulted in reduced inspection requirements as a means to reduce cost. The reduced KSC inspections continued until the Challenger accident in 1986. Various studies and reports following the accident re-emphasized the need for inspections. An intensive review and assessment led to inspection planning for the QPRD based on technical rationale and risk.

In 1990, the NASA Office of Space Flight (OSF) directed KSC to improve operational activities by focusing on Total Quality Management initiatives. KSC chose quality assurance for its improvement efforts. In 1991, the OSF directed KSC to reduce non-critical inspections by 25%. In response, KSC developed a Structured Surveillance program which places quality accountability on the individuals performing the task, focuses mandatory inspection on work with significant risk, uses statistical-based measurement of quality, and establishes a closed-loop, continuous, quality assurance improvement process. The system does not change the inspection requirements by both contractor and government for critical items, but instead presents significant changes in government philosophy for monitoring contractor performance on non-critical items.

This approach involves training the KSC workforce in the philosophy that everyone is responsible for quality, the application of structured surveillance, and the role of total quality assurance. The concept relies more on the individual technicians for quality verification. The system will use measured quality yields in inspection and sampling to identify opportunities for improvement. For each area, samples will be used as weekly indicators instead of acceptance parameters.

To date, results indicate more knowledgeable workers, greater flexibility in quality assurance functions, the establishment of first-time quality metrics, and expanded quality coverage without increasing inspection manpower. Future plans include data collection and analysis technique improvements, report enhancement, continuous improvement of the sampling approach, and further process improvements.

## Variable-Form Data Analysis

Until 1995, KSC used discrete element data as a basis for pass/fail with respect to conformance of specifications. When also used in statistical analysis, this data justified the improvement of several KSC process operations.

Recently, the Industrial Engineering team conceived, designed, developed, and is beginning to implement a variable-form data analysis methodology. This analysis examines data variations for trend analysis which may result in substantial reductions in areas such as direct labor hours, material costs, and amount of rework.

One example, identified by the variable-form data analysis, surfaced during the investigation of processing tasks by Shuttle Materials and Processes engineers. Numerous reworks were occurring because bond test strips failed to meet pull-test strength values. Detailed analysis, as summarized in Figures 3-1 and 3-2, indicated the structural bonding failures resulted from a lack of process capability, largely associated with a particular, two-part epoxy adhesive commonly used in bonds requiring high strength. As a result, a new bonding process has been designed which can potentially reduce rework by 67% and establish stronger structural bonds. Once KSC verifies and records metrics of this process, the next step for process operations improvements will be to strive for zero structural bonding rework.

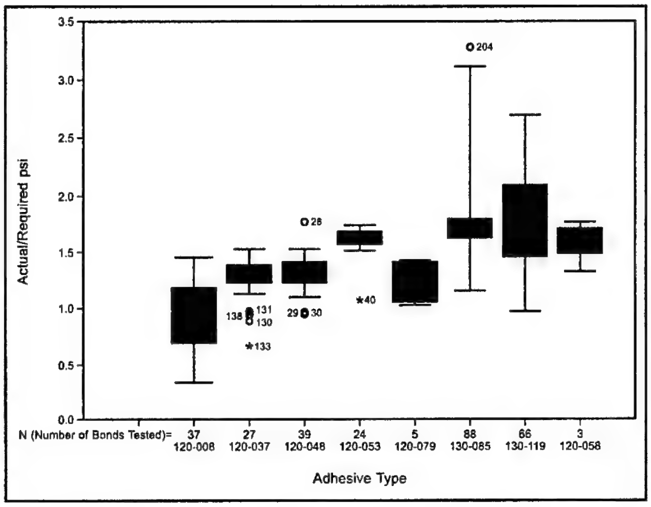



***Figure 3-1. Capability of Individual Bonding Adhesives***

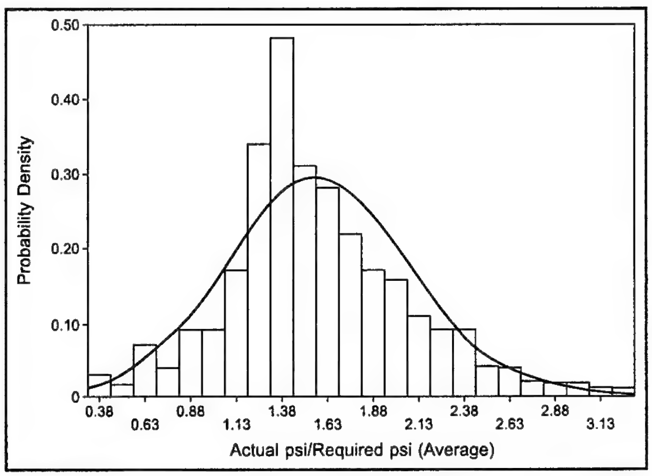



***Figure 3-2. Overall Capability of Structural Bonding Process***

# *Facilities*

## Communications

The communication function at KSC is a critical link to operations. KSC must ensure its users receive the same data upon demand. Each user's project may have its own communication requirements which must be supported during all phases of the life cycle. Despite occasional obstacles of antiquated technology or reduced funding, KSC still maintains all existing capabilities without any discontinuance of operations.

With its established practice of involving the customer in all phases of each project's life cycle, KSC satisfies its users in development and modification. These phases include establishing requirements; performing analysis; reviewing internal and commercial capabilities; and providing periodic reviews for all phases, acquisition, installation, acceptance, and support of a completed project. Communication capabilities at KSC include a fiber optic transmission system which contains more than 13,000 miles of fiber for distribution of voice, data, imaging and video, including 73 cameras at each launch pad; a digital audio and distribution system that connects over 4,300 end-user instruments; a proposed improved radio frequency system for person-to-person communication; a highly-accurate timing system based on two global-positioning stations and a cesium beam clock; and ground systems for the testing of telemetry data and distribution.

## Environmental Control Systems

In the past, KSC used various environmental control systems in its payload processing facilities and buildings. These included pneumatic controls, stand-alone digital controls, and PC-based control systems for monitoring clean rooms. There were separate controls for miscellaneous systems and separate controls for monitoring. In general, these types of controls were unsatisfactory because of unreliable, difficult to control, and out-dated technology. Driven by requirements for improved energy efficiency, more precise operation, and better monitoring capability, KSC selected an integrated, direct-digital, control system for the new Space Station Processing Facility (SSPF).

The SSPF has a single-building automation system capable of integrating all environmental systems within the facility. This user-friendly system interfaces easily with outside systems and networks, is monitored through PC workstations, and informs maintenance personnel of problems by remote paging. In addition, the system has produced large savings over previous systems. Figure 3-3 shows an energy-use comparison of the SSPF with a similar facility using out-dated environmental control systems. Automated controls installed in the lighting system can easily be incorporated into other applications. The new system provides greater flexibility to accommodate the various requirements of customers.

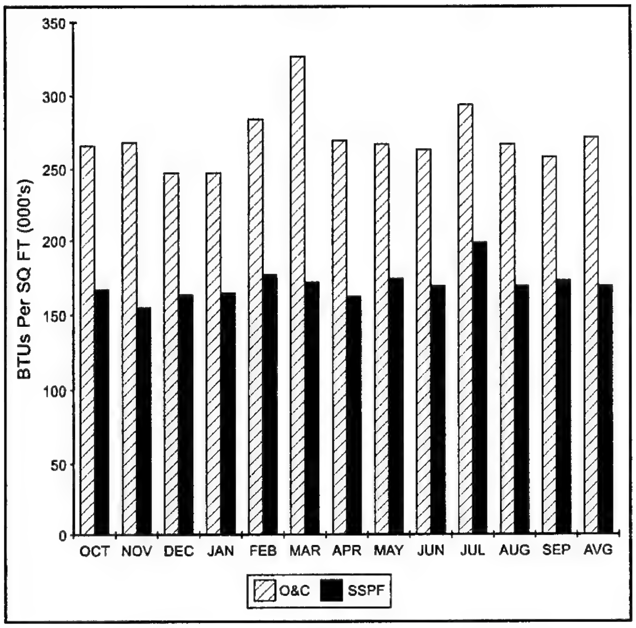



***Figure 3-3. FY96 Energy Use Index Comparison of the Operations & Checkout Building and the Space Station Processing Facility***

## Space Station Processing Facility

The SSPF, a 460,000 square-foot, class 100,000 clean room facility, was built specifically to accommodate shuttle payloads for the ISS. Salient features include a 46,000 square-foot high bay and a 17,000 square-foot low bay for processing ISS elements; 19 off-line labs within the clean work area; air-bearing compatible flooring and pallets; air locks and personnel air showers; high communication rate fiber optic LAN; perimeter tunneling and catwalks to accommodate utilities; and energy-efficient, computer-controlled air conditioning, heating, and lighting equipment.

After thoroughly analyzing the successes and experiences from its previously-designed facilities, KSC based the SSPF's construction on operational efficiency and flexibility, cleanliness, maintenance, and energy efficiency. Design features include installing standard utility interfaces uniformly throughout the processing and office areas, maximizing available floor space by routing cabling, plumbing, and ductwork through tunnels and catwalks, and using air-bearing flooring to permit easy movement of support equipment. Fiber optic LAN optimizes communications throughout the office and processing areas. DC-powered, overhead cranes with digital controllers provide position resolution and control for moving and positioning equipment, fixtures, and space station elements. All fans and compressors are internally located at a single, sound-proof site to avoid the harsh corrosive environment of the region. In addition, the facility takes into account all EPA regulations in its design.

With construction of the SSPF completed, KSC is installing the necessary payload support structures and ground support equipment for the process assembly of the ISS. Dramatic improvements in operational efficiency and flexibility of the SSPF, as compared to other similar facilities, are expected when the ISS program becomes fully operational. The Energy Use Index already shows a 40% reduction in consumption when compared to other comparable facilities.

# *Logistics*

## International Space Station Logistical Support

The logistical teams at KSC have been heavily involved in the Space Shuttle Program (SSP) logistics operations since the origin of the program. As experts, the teams support the program by maintaining flight hardware and ground support equipment and by developing special methods and unique models to effectively manage the logistical needs. KSC is the primary NASA organization which possesses the expertise and emphasis on the logistical elements of complex, small fleet programs and has proven its capabilities on the SSP program.

Based on its track record, KSC anticipates a major role in the logistical support of the International Space Station (ISS) program. KSC recognizes that front-end logistics budgets, planning, and acquisition are often sacrificed for hardware development thrusts. However, delaying logistical capability development after hardware development usually results in significantly higher costs. Therefore, KSC has identified two phases for an integrated logistics system for ISS: long range acquisition logistics and operational logistics support.

The long range acquisition logistics concentrates on the logistical influence during the design and development phases. By influencing supportability and design elements such as material selections, use of COTS hardware and physical maintenance characteristics, a life cycle of stable cost profiles is much more likely. The establishment of affordable, cost-effective maintenance concepts during this phase will pay off during the operational phases.

KSC has identified several important operational logistical elements to support during ISS operations. First, KSC will provide institutional support to prime, product groups; international partners; and principal investigators for elements being processed through the prelaunch, launch, retrieval, landing, and deintegration stages. Second, KSC has established capabilities and processes to enable the provision of additional services such as technical support, calibration, proof-load testing, component repair, and precision cleaning. In addition, KSC is well prepared to provide the management of logistics functions associated with launch-site support.

### Launch Processing System Upgrade Project

KSC currently uses the Launch Processing System (LPS) for its SSP program. Designed, assembled, and programmed with 1970s technologies, KSC successfully used LPS since the early 1980s for the shuttle operations. However, the system lacks modern computing capabilities, uses an arcane programming language, and requires numerous patch-in, subsystem add-ons to maintain its capabilities with changing mission requirements.

In April 1996, an LPS Upgrade Review team studied the present system and made recommendations for an upgrade by establishing project concepts and documenting projected benefits for NASA and United Space Alliance (USA), the new ground and in-flight operations contractor. Within six months, KSC approved the LPS Upgrade Project for FY97 funding.

The LPS Upgrade Project team anticipates the new system will possess enhanced capabilities and future flexibility. By increasing the system reliability and reducing the hardware, software code lines, and facility space, the team projects a yearly operational cost savings of 50% once the new system is fully deployed. In addition, the team predicts a decrease in the number of processing engineers required on site for each operation and a more efficient use of required operations/process engineering personnel.

The LPS Upgrade Project dictates various focuses. These include listening to its users (NASA and USA), and maximizing information transfer from the Air Force's launch facilities and NASA Johnson Space Center's Mission Control regarding upgrade experiences. In addition, the project will focus on COTS and industry standards, and will challenge any requirements which preclude such a focus.

The LPS Upgrade Project must be developed and brought on-line without any negative impacts on the SSP manifest. To achieve this, the team will make small subsystem deliveries every six months, work to minimize complexity and system costs, emphasize the implementation of a real system instead of should-be documentation, and take manageable risks.

## *Management*

### Electronic LogBook

Previously, system engineers used paper log books to record all the daily events. Currently, KSC is changing this method to an electronic PC-based system called Electronic LogBook (ELOG). ELOG consists of two primary tables: the Tag table and the LogBook table. All entries (records) entered into the LogBook table are associated with an existing entry within the Tag table. A unique identifier from the Tag table references each entry through its subject. The LogBook table supports ELOG's relational database and serves as the searchable information storage system where the actual data entry is stored.

ELOG provides a means to conduct consistent, historical trend analysis in a timely manner and produces a wide variety of reports and real-time status. It also provides a storage and retrieval capability for knowledge and experience developed throughout the processing activities. While the majority of the system is installed on the local workstations throughout KSC, the table attachments are centralized on the server where the master copy resides. The system automatically updates the version on a user's workstation by comparing it with the version number on the server.

Currently, ELOG contains more than 10,000 log entries and is growing daily as the system expands throughout KSC. Upgrades in the future will include the scanning of past data from the paper log books previously used.

### Portable Data Collection System

The Portable Data Collection (PDC) allows shop floor technicians and quality assurance personnel to electronically stamp the completion of critical

work steps and enter data into electronic work instruction documents. The system operates through hand-held notepad computers and remote PCs.

The development and eventual commercialization of an electronic stamp to an electronic document resulted from a Small Business Innovative Research (SBIR) contract initiated in May 1994 between KSC and Sentel Corporation. Phase II, completed in May 1996, developed the capability to apply an electronic stamp to an electronic document. The integration of the technique into real-time documentation at KSC proved its validity and showed a strong potential for commercialization.

The main components of the PDC system consist of a Central Data Server, which includes a desktop PC running Windows NT and software consisting of a form conversion S/W Module; a network communications control S/W Module; a document format conversion S/W Module; and stamp utilities. The Portable Data Terminal (PDT) consists of a laptop PC or Notepad running Windows for Workgroups or Windows 95, an electronic stamp, a stamp reader, and PDT-executable software.

KSC chose the Work Authorization Document (WAD), currently used in Payload Processing Operations, as the test document process. The PDC system process consists of converting an approved WAD from a Microsoft Word document into a format which is executable on a PDT; executing the WAD using a PDT; and converting the as-run document into a portable document format (.pdf file).

Time-savings expected from processing the WADs includes the elimination of printing, scanning, and distributing the documents; gathering information for incident investigations; and management reporting. Users instantly see changes made to the documents and can incorporate deviations directly into the document rather than use an attachment. The need to carry multiple stamps and ink pads are eliminated, while overall accuracy of the operation has improved.

Sentel Corporation is currently marketing the electronic stamp and stamp reader devices. The PDC system complements the Wireless Information Network, currently being developed under a separate SBIR contract, which will incorporate KSC's existing Problem Reporting and Corrective Action system.

## Spacelab Integration Process

KSC is responsible for accepting, integrating, and testing spacelab experiments from numerous customers in preparation for shuttle launches. Prior to 1992, these experiments followed a 55-week integration flow template which guided the experiment from initial staging of flight components through launch. Customers viewed this integration flow as too lengthy, complex, costly, and inflexible. In response to customer concerns, KSC conducted a study to identify which activities could be compressed, performed in parallel, or eliminated.

One activity, power-up testing, occurred at several levels during the integration flow. These tests verified the interfaces from the experiment to the carrier, the carrier to the spacelab, and the spacelab to the orbiter. As the experiment's components grew in complexity, more personnel were needed to monitor the tests. This in turn elevated the testing costs at each level. Therefore, any reductions in the amount of power-up testing, particularly in the later stages of the integration flow, would result in significant savings of time and cost.

The following changes to the integration flow streamlined the power-up testing requirements:

- By performing the functional testing of the experiment in series, potential problems arising from powered hardware interaction were avoided. However, some experiments do not have common interfaces and therefore cannot interact. In those situations, KSC identifies these experiments and now tests them in parallel.
- All payload configurations undergo a Cargo Integration and Test Equipment (CITE) test prior to installation into the orbiter. This test verifies that all interfaces to the orbiter are functional and prevents damage to the orbiter due to misconfigured payload interfaces. In cases of a reflown payload, CITE tests may be eliminated since it is unnecessary to verify interfaces which functioned properly on a previous flight. This eliminates up to seven days of power-up testing.
- Previously, it took three to ten days to balance the flow in the various segments of the freon cooling system. By using a flow-balance metering unit to interface with the LabView software package, power-up testing decreased to just one day.

- The Mission Sequence Test (MST) usually took three days to complete. By using flight-like procedures, MST verified that the integrated payload operations would not exceed the spacelab operating envelope. However, experience gained from over 16 spacelab missions greatly reduced the need for MST. A new Integrated Compatibility Test now provides representative power, data flow, and thermal conditions in one testing day.

Individual measurements of the racks and overhead containers determined the weight and Center of Gravity (CG) of the integrated module for the spacelab module missions. By making one weight and CG measurement of the integrated module, over 500 workforce hours were eliminated. The combined effect of all the above changes resulted in an overall reduction from 55 to 40 weeks, and a decrease in the workforce requirement by 22%.

# Appendix A
## *Table of Acronyms*

| Acronym | Definition |
|---|---|
| AMU | Applied Meteorology Unit |
| AO | Announcement of Opportunity |
| APU | Auxiliary Power Unit |
| ARMS | Automated Requirements Management System |
| CASPR | Computer Aided Scheduling and Planning Resources |
| CBT | Computer Based Training |
| CG | Center of Gravity |
| CITE | Cargo Integration and Test Equipment |
| COTS | Commercial Off-The-Shelf |
| DR | Discrepancy Reports |
| EDCS | Electronic Data Control System |
| ELOG | Electronic LogBook |
| ELVIS | Expert Learning for Vehicle Instruction by Simulation |
| GPSS | Ground Processing Scheduling System |
| GSRP | Ground Safety Review Process |
| ISS | International Space Station |
| IT | Information Technology |
| IWCS | Integrated Work Control System |
| KSC | Kennedy Space Center |
| LAN | Local Area Network |
| LPS | Launch Processing System |
| LRU | Line Replaceable Unit |
| LSSM | Launch Site Support Manager |
| MST | Mission Sequence Test |
| NASA | National Aeronautics and Space Administration |
| NCC | Network Control Center |
| NSLD | NASA Shuttle Logistics Depot |
| OEM | Original Equipment Manufacturer |
| OMRS | Operations and Maintenance Requirements and Specifications |
| OSF | Office of Space Flight |

| Acronym | Definition |
|---|---|
| PCGOAL | Personal Computer Ground Operations Aerospace Language |
| PDC | Portable Data Collection |
| PDM | Predictive Maintenance |
| PDT | Portable Data Terminal |
| PM | Preventive Maintenance |
| PON | Payload Operations Network |
| POS | Probability of Sufficiency |
| PR | Problem Reports |
| QPRD | Quality Planning and Requirements Document |
| RCM | Reliability Centered Maintenance |
| RID | Rack Insertion Device |
| SBIR | Small Business Innovative Research |
| SFC | Shop Floor Control |
| SFC/DC | Shop Floor Control/Data Collection |
| SSP | Space Shuttle Program |
| SSPF | Space Station Processing Facility |
| TPCO | Technology Programs and Commercialization Office |
| USA | United Space Alliance |
| WAD | Work Authorization Document |
| WPSS | Work Preparation Support System |

# Appendix B

## *BMP Survey Team*

| Team Member | Activity | Function |
|---|---|---|
| **Larry Robertson**<br>(812) 854-5336 | **Crane Division**<br>**Naval Surface Warfare Center**<br>Crane, IN | **Team Chairman** |
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### Tech Track Team #1

| Team Member | Activity | Function |
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| **Nick Keller**<br>(812) 854-5331 | **Naval Surface Warfare Center**<br>Crane, IN | |
| **Travis Walton**<br>(301) 405-3883 | **University of Maryland**<br>College Park, MD | |

### Tech Track Team #2

| Team Member | Activity | Function |
|---|---|---|
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| **Richard Rumpf**<br>(703) 351-5080 | **Rumpf Associates International**<br>Arlington, VA | |
| **Anne Marie SuPrise**<br>(301) 403-8100 | **BMP Center of Excellence**<br>College Park, MD | |
| **Jack Tamargo**<br>(707) 642-4267 | **BMP Satellite Center Manager**<br>Vallejo, CA | |

## Tech Track Team #3

| | | |
|---|---|---|
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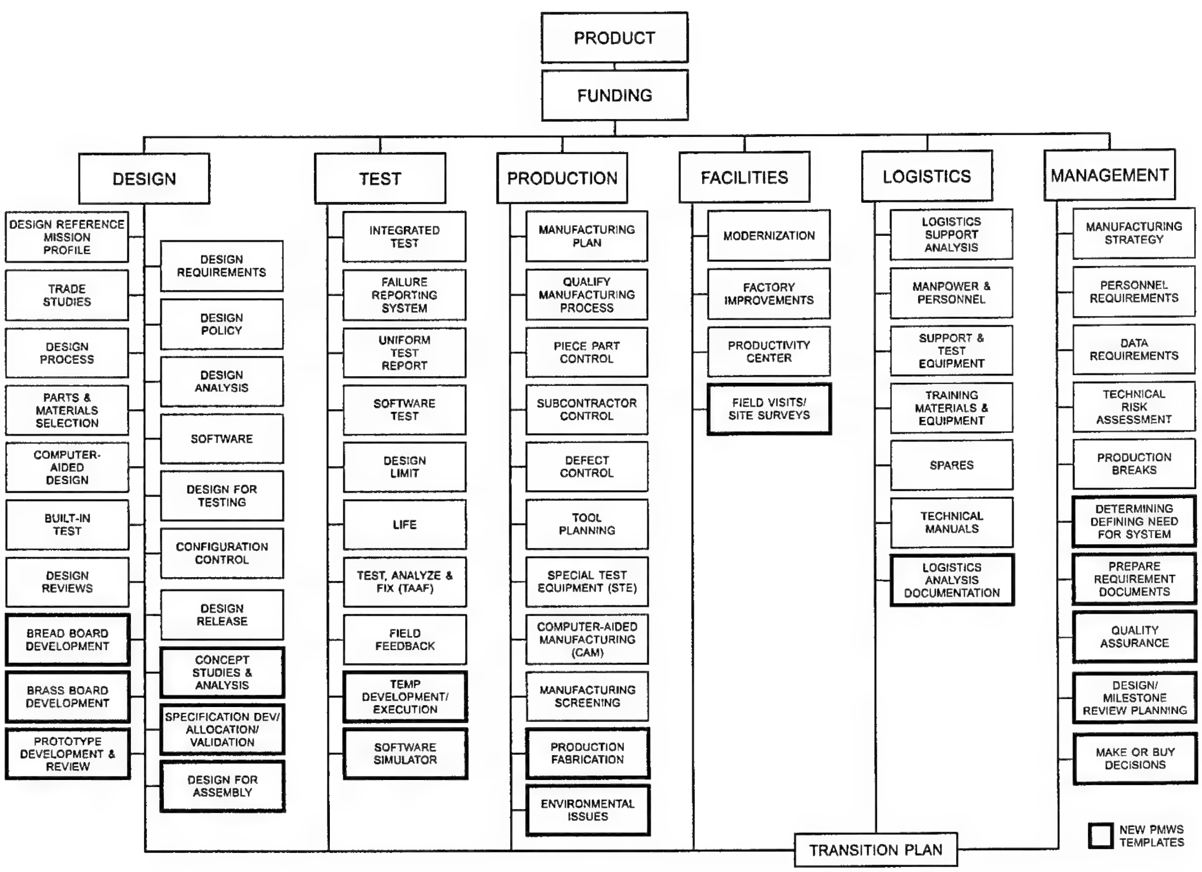
| Larry Halbig<br>(317) 306-3838 | Naval Air Warfare Center<br>Indianapolis, IN | |
| Don Hill<br>(317) 306-3781 | Naval Air Warfare Center<br>Indianapolis, IN | |
| Ron Parise<br>(301) 286-3896 | Computer Sciences Corporation<br>Greenbelt, MD | |

# Appendix C
## *Critical Path Templates and BMP Templates*

This survey was structured around and concentrated on the functional areas of design, test, production, facilities, logistics, and management as presented in the Department of Defense 4245.7-M, *Transition from Development to Production* document. This publication defines the proper tools—or templates—that constitute the critical path for a successful material acquisition program. It describes techniques for improving the acquisition process by addressing it as an *industrial* process that focuses on the product's design, test, and production phases which are interrelated and interdependent disciplines.

The BMP program has continued to build on this knowledge base by developing 17 new templates that complement the existing DOD 4245.7-M templates. These BMP templates address new or emerging technologies and processes.

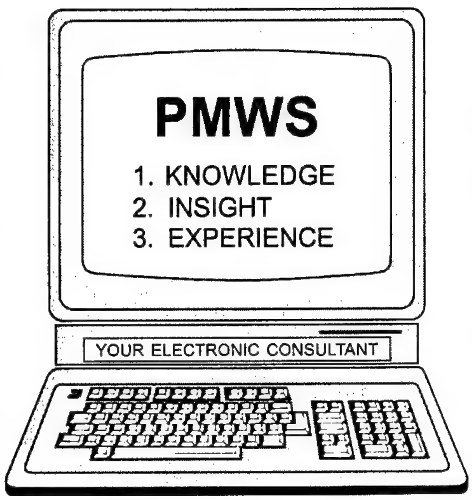
### "CRITICAL PATH TEMPLATES FOR TRANSITION FROM DEVELOPMENT TO PRODUCTION"



# Appendix D

## *BMPnet and the Program Manager's WorkStation*

The BMPnet, located at the Best Manufacturing Practices Center of Excellence (BMPCOE) in College Park, Maryland, supports several communication features. These features include the Program Manager's WorkStation (**PMWS**), electronic mail and file transfer capabilities, as well as access to Special Interest Groups (SIGs) for specific topic information and communication. The BMPnet can be accessed through the World Wide Web (at http://www.bmpcoe.org), through free software that connects directly over the Internet or through a modem. The PMWS software is also available on CD-ROM.




PMWS provides users with timely acquisition and engineering information through a series of interrelated software environments and knowledge-based packages. The main components of PMWS are KnowHow, SpecRite, the Technical Risk Identification and Mitigation System (TRIMS), and the BMP Database.

**KnowHow** is an intelligent, automated program that provides rapid access to information through an intelligent search capability. Information currently available in KnowHow handbooks includes Acquisition Streamlining, Non-Development Items, Value Engineering, NAVSO P-6071 (Best Practices Manual), MIL-STD-2167/2168 and the DoD 5000 series documents. KnowHow cuts document search time by 95%, providing critical, user-specific information in under three minutes.

**SpecRite** is a performance specification generator based on expert knowledge from all uniformed services. This program guides acquisition personnel in creating specifications for their requirements, and is structured for the build/approval process. SpecRite's knowledge-based guidance and assistance structure is modular, flexible, and provides output in MIL-STD 961D format in the form of editable WordPerfect® files.

**TRIMS**, based on DoD 4245.7-M (the transition templates), NAVSO P-6071, and DoD 5000 event-oriented acquisition, helps the user identify and rank a program's high-risk areas. By helping the user conduct a full range of risk assessments throughout the acquisition process, TRIMS highlights areas where corrective action can be initiated before risks develop into problems. It also helps users track key project documentation from concept through production including goals, responsible personnel, and next action dates for future activities.

The **BMP Database** contains proven best practices from industry, government, and the academic communities. These best practices are in the areas of design, test, production, facilities, management, and logistics. Each practice has been observed, verified, and documented by a team of government experts during BMP surveys.

Access to the BMPnet through dial-in or on Internet requires a special modem program. This program can be obtained by calling the BMPnet Help Desk at (301) 403-8179 or it can be downloaded from the World Wide Web at http://www.bmpcoe.org. To receive a user/e-mail account on the BMPnet, send a request to helpdesk@bmpcoe.org.

# Appendix E

## *Best Manufacturing Practices Satellite Centers*

There are currently six Best Manufacturing Practices (BMP) satellite centers that provide representation for and awareness of the BMP program to regional industry, government and academic institutions. The centers also promote the use of BMP with regional Manufacturing Technology Centers. Regional manufacturers can take advantage of the BMP satellite centers to help resolve problems, as the centers host informative, one-day regional workshops that focus on specific technical issues.

Center representatives also conduct BMP lectures at regional colleges and universities; maintain lists of experts who are potential survey team members; provide team member training; identify regional experts for inclusion in the BMPnet SIG e-mail; and train regional personnel in the use of BMP resources such as the BMPnet.

The six BMP satellite centers include:

<u>**California**</u>

**Chris Matzke**
BMP Satellite Center Manager
Naval Warfare Assessment Division
Code QA-21, P. O. Box 5000
1456 Mariposa Drive
Corona, CA 91718
(909) 273-4992
FAX: (909) 273-5315
cmatzke@bmpcoe.org

**Jack Tamargo**
BMP Satellite Center Manager
257 Cottonwood Drive
Vallejo, CA 94591
(707) 642-4267
jtamargo@bmpcoe.org

<u>**District of Columbia**</u>

**Brad Botwin**
BMP Satellite Center Manager
U.S. Department of Commerce
14th Street & Constitution Avenue, NW
Room 3878
Washington, DC 20230
(202) 482-4060
FAX: (202) 482-5650
bbotwin@bxa.doc.gov

<u>**Illinois**</u>

**Dean Zaumseil**
BMP Satellite Center Manager
Rock Valley College
3301 North Mulford Road
Rockford, IL 61114
(815) 654-5530
FAX: (815) 654-4459
adme3dz@rvcux1.rvc.cc.il.us

<u>**Pennsylvania**</u>

**Sherrie Snyder**
BMP Satellite Center Manager
MANTEC, Inc.
P.O. Box 5046
York, PA 17405
(717) 843-5054
FAX: (717) 854-0087
snyderss@mantec.org

<u>**Tennessee**</u>

**Tammy Graham**
BMP Satellite Center Manager
Martin Marietta Energy Systems
P. O. Box 2009, Bldg. 9737
MS 8091
Oak Ridge, TN 37831
(615) 576-5532
FAX: (615) 574-2000
tgraham@bmpcoe.org

# Appendix F

## *Navy Manufacturing Technology Centers of Excellence*

The Navy Manufacturing Sciences and Technology Program established the following Centers of Excellence (COEs) to provide focal points for the development and technology transfer of new manufacturing processes and equipment in a cooperative environment with industry, academia, and Navy centers and laboratories. These COEs are consortium-structured for industry, academia, and government involvement in developing and implementing technologies. Each COE has a designated point of contact listed below with the individual COE information.

### Best Manufacturing Practices Center of Excellence

The Best Manufacturing Practices Center of Excellence (BMPCOE) provides a national resource to identify and promote exemplary manufacturing and business practices and to disseminate this information to the U.S. Industrial Base. The BMPCOE was established by the Navy's BMP program, Department of Commerce's National Institute of Standards and Technology, and the University of Maryland at College Park, Maryland. The BMPCOE improves the use of existing technology, promotes the introduction of improved technologies, and provides non-competitive means to address common problems, and has become a significant factor in countering foreign competition.

Point of Contact:
Mr. Ernie Renner
Best Manufacturing Practices Center of Excellence
4321 Hartwick Road
Suite 400
College Park, MD 20740
(301) 403-8100
FAX: (301) 403-8180
ernie@bmpcoe.org

### Center of Excellence for Composites Manufacturing Technology

The Center of Excellence for Composites Manufacturing Technology (CECMT) provides a national resource for the development and dissemination of composites manufacturing technology to defense contractors and subcontractors. The CECMT is managed by the GreatLakes Composites Consortium and represents a collaborative effort among industry, academia, and government to develop, evaluate, demonstrate, and test composites manufacturing technologies. The technical work is problem-driven to reflect current and future Navy needs in the composites industrial community.

Point of Contact:
Dr. Roger Fountain
Center of Excellence for Composites Manufacturing Technology
103 Trade Zone Drive
Suite 26C
West Columbia, SC 29170
(803) 822-3705
FAX: (803) 822-3730
frglcc@aol.com

### Electronics Manufacturing Productivity Facility

The Electronics Manufacturing Productivity Facility (EMPF) identifies, develops, and transfers innovative electronics manufacturing processes to domestic firms in support of the manufacture of affordable military systems. The EMPF operates as a consortium comprised of industry, university, and government participants, led by the American Competitiveness Institute under a CRADA with the Navy.

Point of Contact:
Mr. Alan Criswell
Electronics Manufacturing Productivity Facility
Plymouth Executive Campus
Bldg 630, Suite 100
630 West Germantown Pike
Plymouth Meeting, PA 19462
(610) 832-8800
FAX: (610) 832-8810
http://www.engriupui.edu/empf/

### National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology (NCEMT) provides a national center for the development, dissemination, and implementation of advanced technologies for metalworking products and processes. The NCEMT, operated by Concurrent Technologies Corporation, helps the Navy and defense contractors improve

manufacturing productivity and part reliability through development, deployment, training, and education for advanced metalworking technologies.

Point of Contact:
Mr. Richard Henry
National Center for Excellence in Metalworking Technology
1450 Scalp Avenue
Johnstown, PA 15904-3374
(814) 269-2532
FAX: (814) 269-2799
henry@ctc.com

### Navy Joining Center

The Navy Joining Center (NJC) is operated by the Edison Welding Institute and provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities. The NJC works with the Navy to determine and evaluate joining technology requirements and conduct technology development and deployment projects to address these issues.

Point of Contact:
Mr. David P. Edmonds
Navy Joining Center
1100 Kinnear Road
Columbus, OH 43212-1161
(614) 487-5825
FAX: (614) 486-9528
dave_edmonds@ewi.org

### Energetics Manufacturing Technology Center

The Energetics Manufacturing Technology Center (EMTC) addresses unique manufacturing processes and problems of the energetics industrial base to ensure the availability of affordable, quality energetics. The focus of the EMTC is on process technology with a goal of reducing manufacturing costs while improving product quality and reliability. The COE also maintains a goal of development and implementation of environmentally benign energetics manufacturing processes.

Point of Contact:
Mr. John Brough
Energetics Manufacturing Technology Center
Indian Head Division
Naval Surface Warfare Center
Indian Head, MD 20640-5035
(301) 743-4417
DSN: 354-4417
FAX: (301) 743-4187
mt@command.nosih.sea06.navy.mil

### Manufacturing Science and Advanced Materials Processing Institute

The Manufacturing Science and Advanced Materials Processing Institute (MS&MPI) is comprised of three centers including the National Center for Advanced Drivetrain Technologies (NCADT), The Surface Engineering Manufacturing Technology Center (SEMTC), and the Laser Applications Research Center (LaserARC). These centers are located at The Pennsylvania State University's Applied Research Laboratory. Each center is highlighted below.

Point of Contact for MS&MPI:
Mr. Dennis Herbert
Manufacturing Science and Advanced Materials Processing Institute
ARL Penn State
P.O. Box 30
State College, PA 11804-0030
(814) 865-8205
FAX: (814) 863-0673
dbh5@psu.edu

- **National Center for Advanced Drivetrain Technologies**
  The NCADT supports DoD by strengthening, revitalizing, and enhancing the technological capabilities of the U.S. gear and transmission industry. It provides a site for neutral testing to verify accuracy and performance of gear and transmission components.

  Point of Contact for NCADT:
  Dr. Suren Rao
  National Center for Advanced Drivetrain Technologies
  ARL Penn State
  P.O. Box 30
  State College, PA 16804-0030
  (814) 865-3537
  FAX: (814) 863-1183
  http://www.arl.psu.edu/drivetrain_center.html/

- **Surface Engineering Manufacturing Technology Center**

  The SEMTC enables technology development in surface engineering—the systematic and rational modification of material surfaces to provide desirable material characteristics and performance. This can be implemented for complex optical, electrical, chemical, and mechanical functions or products that affect the cost, operation, maintainability, and reliability of weapon systems.

  Point of Contact for SEMTC:
  Surface Engineering Manufacturing Technology Center
  Dr. Maurice F. Amateau
  SEMTC/Surface Engineering Center
  P.O. Box 30
  State College, PA 16804-0030
  (814) 863-4214
  FAX: (814) 863-0006
  http://www/arl.psu.edu/divisions/arl_org.html

- **Laser Applications Research Center**

  The LaserARC is established to expand the technical capabilities of DOD by providing access to high-power industrial lasers for advanced material processing applications. LaserARC offers basic and applied research in laser-material interaction, process development, sensor technologies, and corresponding demonstrations of developed applications.

  Point of Contact for LaserARC:
  Mr. Paul Denney
  Laser Center
  ARL Penn State
  P.O. Box 30
  State College, PA 16804-0030
  (814) 865-2934
  FAX: (814) 863-1183
  http://www/arl.psu.edu/divisions/arl_org.html

**Gulf Coast Region Maritime Technology Center**

The Gulf Coast Region Maritime Technology Center (GCRMTC) is located at the University of New Orleans and will focus primarily on product developments in support of the U.S. shipbuilding industry. A sister site at Lamar University in Orange, Texas will focus on process improvements.

Point of Contact:
Dr. John Crisp
Gulf Coast Region Maritime Technology Center
University of New Orleans
Room N-212
New Orleans, LA 70148
(504) 286-3871
FAX: (504) 286-3898

# Appendix G
## *Completed Surveys*

As of this publication, 87 surveys have been conducted by BMP at the companies listed below. Copies of older survey reports may be obtained through DTIC or by accessing the BMPnet. Requests for copies of recent survey reports or inquiries regarding the BMPNET may be directed to:


Best Manufacturing Practices Program
4321 Hartwick Rd., Suite 400
College Park, MD 20740
Attn: Mr. Ernie Renner, Director
Telephone: 1-800-789-4267
FAX: (301) 403-8180
ernie@bmpcoe.org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|---|---|
| **1985** | Litton Guidance & Control Systems Division - Woodland Hills, CA |
| **1986** | Honeywell, Incorporated Undersea Systems Division - Hopkins, MN (Alliant TechSystems, Inc.)<br>Texas Instruments Defense Systems & Electronics Group - Lewisville, TX<br>General Dynamics Pomona Division - Pomona, CA<br>Harris Corporation Government Support Systems Division - Syosset, NY<br>IBM Corporation Federal Systems Division - Owego, NY<br>Control Data Corporation Government Systems Division - Minneapolis, MN |
| **1987** | Hughes Aircraft Company Radar Systems Group - Los Angeles, CA<br>ITT Avionics Division - Clifton, NJ<br>Rockwell International Corporation Collins Defense Communications - Cedar Rapids, IA<br>UNISYS Computer Systems Division - St. Paul, MN (Paramax) |
| **1988** | Motorola Government Electronics Group - Scottsdale, AZ<br>General Dynamics Fort Worth Division - Fort Worth, TX<br>Texas Instruments Defense Systems & Electronics Group - Dallas, TX<br>Hughes Aircraft Company Missile Systems Group - Tucson, AZ<br>Bell Helicopter Textron, Inc. - Fort Worth, TX<br>Litton Data Systems Division - Van Nuys, CA<br>GTE $C^3$ Systems Sector - Needham Heights, MA |
| **1989** | McDonnell-Douglas Corporation McDonnell Aircraft Company - St. Louis, MO<br>Northrop Corporation Aircraft Division - Hawthorne, CA<br>Litton Applied Technology Division - San Jose, CA<br>Litton Amecom Division - College Park, MD<br>Standard Industries - LaMirada, CA<br>Engineered Circuit Research, Incorporated - Milpitas, CA<br>Teledyne Industries Incorporated Electronics Division - Newbury Park, CA<br>Lockheed Aeronautical Systems Company - Marietta, GA<br>Lockheed Corporation Missile Systems Division - Sunnyvale, CA<br>Westinghouse Electronic Systems Group - Baltimore, MD<br>General Electric Naval & Drive Turbine Systems - Fitchburg, MA<br>Rockwell International Corporation Autonetics Electronics Systems - Anaheim, CA<br>TRICOR Systems, Incorporated - Elgin, IL |
| **1990** | Hughes Aircraft Company Ground Systems Group - Fullerton, CA<br>TRW Military Electronics and Avionics Division - San Diego, CA<br>MechTronics of Arizona, Inc. - Phoenix, AZ<br>Boeing Aerospace & Electronics - Corinth, TX<br>Technology Matrix Consortium - Traverse City, MI<br>Textron Lycoming - Stratford, CT |

| | |
|---|---|
| **1991** | *Resurvey of Litton Guidance & Control Systems Division* - Woodland Hills, CA<br>Norden Systems, Inc. - Norwalk, CT<br>Naval Avionics Center - Indianapolis, IN<br>United Electric Controls - Watertown, MA<br>Kurt Manufacturing Co. - Minneapolis, MN<br>MagneTek Defense Systems - Anaheim, CA<br>Raytheon Missile Systems Division - Andover, MA<br>AT&T Federal Systems Advanced Technologies and AT&T Bell Laboratories - Greensboro, NC and Whippany, NJ<br>*Resurvey of Texas Instruments Defense Systems & Electronics Group* - Lewisville, TX |
| **1992** | Tandem Computers - Cupertino, CA<br>Charleston Naval Shipyard - Charleston, SC<br>Conax Florida Corporation - St. Petersburg, FL<br>Texas Instruments Semiconductor Group Military Products - Midland, TX<br>Hewlett-Packard Palo Alto Fabrication Center - Palo Alto, CA<br>Watervliet U.S. Army Arsenal - Watervliet, NY<br>Digital Equipment Company Enclosures Business - Westfield, MA and Maynard, MA<br>Computing Devices International - Minneapolis, MN<br>*(Resurvey of Control Data Corporation Government Systems Division)*<br>Naval Aviation Depot Naval Air Station - Pensacola, FL |
| **1993** | NASA Marshall Space Flight Center - Huntsville, AL<br>Naval Aviation Depot Naval Air Station - Jacksonville, FL<br>Department of Energy Oak Ridge Facilities (Operated by Martin Marietta Energy Systems, Inc.) - Oak Ridge, TN<br>McDonnell Douglas Aerospace - Huntington Beach, CA<br>Crane Division Naval Surface Warfare Center - Crane, IN and Louisville, KY<br>Philadelphia Naval Shipyard - Philadelphia, PA<br>R. J. Reynolds Tobacco Company - Winston-Salem, NC<br>Crystal Gateway Marriott Hotel - Arlington, VA<br>Hamilton Standard Electronic Manufacturing Facility - Farmington, CT<br>Alpha Industries, Inc. - Methuen, MA |
| **1994** | Harris Semiconductor - Melbourne, FL<br>United Defense, L.P. Ground Systems Division - San Jose, CA<br>Naval Undersea Warfare Center Division Keyport - Keyport, WA<br>Mason & Hanger - Silas Mason Co., Inc. - Middletown, IA<br>Kaiser Electronics - San Jose, CA<br>U.S. Army Combat Systems Test Activity - Aberdeen, MD<br>Stafford County Public Schools - Stafford County, VA |
| **1995** | Sandia National Laboratories - Albuquerque, NM<br>Rockwell Defense Electronics Collins Avionics & Communications Division - Cedar Rapids, IA<br>*(Resurvey of Rockwell International Corporation Collins Defense Communications)*<br>Lockheed Martin Electronics & Missiles - Orlando, FL<br>McDonnell Douglas Aerospace (St. Louis) - St. Louis, MO<br>*(Resurvey of McDonnell-Douglas Corporation McDonnell Aircraft Company)*<br>Dayton Parts, Inc. - Harrisburg, PA<br>Wainwright Industries - St. Peters, MO<br>Lockheed Martin Tactical Aircraft Systems - Fort Worth, TX<br>*(Resurvey of General Dynamics Fort Worth Division)*<br>Lockheed Martin Government Electronic Systems - Moorestown, NJ<br>Sacramento Manufacturing and Services Division - Sacramento, CA<br>JLG Industries, Inc. - McConnellsburg, PA |
| **1996** | City of Chattanooga - Chattanooga, TN<br>Mason & Hanger Corporation - Pantex Plant - Amarillo, TX<br>Nascote Industries, Inc. - Nashville, IL<br>Weirton Steel Corporation - Weirton, WV<br>NASA Kennedy Space Center - Cape Canaveral, FL |